LACIE-00418
JSC-11663

LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)

NASA NOAA USDA

PHASE I
EVALUATION REPORT

National Aeronautics and Space Administration
LYNDON B. JOHNSON SPACE CENTER
Houston, Texas

May, 1976

(NASA-TM-X-74226) LARGE AREA CROP INVENTORY EXPERIMENT (LACIE). PHASE 1: EVALUATION REPORT (NASA) 100 p HC A05/MF A01 CSCL 02C
N77-12481
Unclas
G3/43 55770

LARGE AREA CROP INVENTORY EXPERIMENT

(LACIE)

PHASE I

EVALUATION REPORT

APPROVED BY:

R. B. MacDonald

R. B. MacDonald
Manager, Large Area Crop Inventory Experiment

MAY 1976

CONTENTS

TABLES

FIGURES

GLOSSARY OF LACIE TERMS

ABBREVIATIONS AND ACRONYMS

Biological Stage — Specific stages of development of a crop which can be recognized by a major change in plant structure, i.e., emergence after germination, jointing, heading, etc. and are represented by integers on the Robertson Biometeorological Time Scale.

Biowindow — A Landsat data acquisition period that is tied to the biostages of wheat development. The LACIE approach is based upon the judgment that wheat can be spectrally separated adequately from other crops by analysis of up to four acquisitions of Landsat data during the growing season. The biowindow opening and closing dates may be updated if there is a significant lag or advancement in the current crop growth. The sequence chosen includes acquisitions during the following biowindows:

a. Crop establishment - from planting to the booting stage

b. Green - from the booting stage to the heading stage

c. Heading - from the heading stage to the soft dough stage

d. Mature - from the soft dough stage to the harvest stage

Blind Site	A LACIE sample segment, chosen at random after normal analysis, used for testing classification performance
CCEA	Center for Climatic and Environmental Assessment, an organization of the National Oceanic and Atmospheric Administration (NOAA), Columbia, Missouri
Classification	In computer-aided analysis of remotely sensed data, the process of assigning data points to specified classes by a testing process in which the spectral properties of each unknown data point are compared with spectral properties typical of the subject being classified
Classification Error	Classification error is a measure of the degree to which the LACIE Classification and Mensuration Subsystem (CAMS) can estimate the wheat area in one or more LACIE samples.
Crop Calendar	A calendar depicting the growth-development or biological stages of the major crop types within a specified region.
Crop Calendar Adjustment	An adjustment made, on the basis of current weather, to the normal crop calendar
Crop Reporting District	A geographical area used by the U.S. Department of Agriculture for the collection and reporting of agricultural information. Each district consists of several counties.

GSFC	Goddard Space Flight Center, a NASA installation in Greenbelt, Maryland
ITS	Intensive Test Sites; U.S. and Canadian locations in which detailed crop information is collected by using ground and airborne equipment
JSC	The Lyndon B. Johnson Space Center, a NASA installation in Houston, Texas
LACIE	Large Area Crop Inventory Experiment
Landsat	Formerly the Earth Resources Technology Satellite (ERTS). This earth-observing satellite operates in a circular, sun-synchronous, near-polar orbit at an altitude of approximately 915 km (494 n.mi.). It orbits the earth 14 times a day and views the same scene every 18 days.
Landsat Data Set	The electronic or film products produced for a particular acquisition of a sample segment
Landsat Scene	The collection of the image data of one nominal framing area (185 km square) of the earth's surface; this includes data from each of four spectral bands or channels on the satellite multispectral scanner.
Mensuration	The act of measuring, in the case of LACIE, measuring surface area in a particular crop
Multispectral	Pertaining to radiation from several discrete bands of the electromagnetic spectrum

Multispectral Scanner or MSS	Multispectral scanner system sometimes referred to simply as the multispectral scanner is the remote sensing instrument on Landsat that measures reflected sunlight in various spectral bands or wavelengths.
Multitemporal Analysis	Analysis of data sets over the same area acquired at different times.
NASA	National Aeronautics and Space Administration
n.mi.	Nautical mile. Equivalent to 1/60° at the earth equator, or approximately 1852 meters (6076 ft.)
NOAA	National Oceanic and Atmospheric Administration of the U.S. Department of Commerce.
Nonsupervised Classification	A procedure by which multispectral data are grouped into spectrally similar clusters.
Pixel	Picuure element; refers to one instantaneous field of view (IFOV) as recorded by the multispectral scanner system. On the Landsat system it is equivalent to approximately 0.44 hectare (1.09 acres). One Landsat frame contains approximately 7.36×10^6 pixels.
R&D	Research and Development
RT&E	Research, Test, and Evaluation

Sample Segment	A 5x6 n.mi. area selected by a stratified random sampling. Information on this area is recorded by the multispectral scanner and transformed into computer compatible tapes and film products.
Sampling Error	A measure of the degree to which the wheat area in the LACIE sample segments represents the wheat area contained in the survey region being sampled
Scene Registration	The process of superimposing points on two data sets taken at different times
Signature Extension	The analysis process using the spectral characteristics or "signature" of one sample segment to perform the classification on another sample segment
SRS	Statistical Reporting Service, an agency of the U.S. Department of Agriculture
Supersite	A particular intensive test site for which additional ground data, such as radiation measurements, are acquired. Currently, there are three supersites: Williams County, N.D., Hand County, S.D., and Finney County, Kansas
Supervised Classification	A procedure used in data processing in which remotely sensed data of known classes are used to establish the decision logic from which unclassified data are assigned to classes.

Test Field	The spatial sample of digital data of a known ground feature selected by the investigator which is used to validate the statistical parameters generated from training field samples.
Training Field	The spatial sample of digital data of a known ground feature selected by the analyst, from which the spectral characteristics are computed for use in supervised multispectral classification of remotely sensed data. The statistics associated with training fields provide the input to "train" the computer to discriminate between different classes in the scene.
USDA	United States Department of Agriculture
WMO	World Meteorological Organization

SECTION 1.0
INTRODUCTION

1.1 GENERAL

The purpose of this report is to provide senior managers in participating LACIE agencies with an evaluation of the experiment. While the main thrust of the report is the evaluation, a brief synopsis of actual achievements is provided as a basis for the evaluation.

The Large Area Crop Inventory Experiment (LACIE) is a cooperative project of the U.S. Department of Agriculture (USDA), the National Aeronautics and Space Administration (NASA), and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce. The major goals of LACIE are:

1. Evaluate and demonstrate the capability of existing technology (remote sensing, data processing and analysis, and other associated technologies) to make improved worldwide crop-production information available to decision makers in a cost-effective manner; this test of technology is to be conducted in a quasi-operational environment.

2. Research and develop alternate approaches and techniques which, upon evaluation, are qualified to be incorporated into the LACIE quasi-operational system where required to meet performance goals or to improve efficiency.

The experiment will span approximately 3-1/2 years, and will progress from Phase I, which concentrated on a system test to

determine wheat areal extent within selected wheat growing regions of the U.S.[1], recognition analyses in selected other areas, and yield model development and yield feasibility determinations over selected regions in the U.S.; through Phases II and III, which will test LACIE capabilities to develop area, yield, and production estimates for other major wheat-producing areas of the world in a quasi-operational mode.

Evaluation reports are scheduled at the completion of each of the three phases of LACIE. These reports are intended to provide executive-level managers of the participating agencies with information to support decisions related to future agency commitments and also to evaluate how well the objectives are met during the period covered by the report.

The intent in this report is to document the results of Phase I of LACIE. Results on the accuracy of the estimates are treated in summary fashion in the body of the report, and in more detail in the appendices.

The scope of this report represents the progress during Phase I of LACIE. However, to present a complete synopsis of activity to date, brief mention is made of key events before the initiation of Phase I of the experiment.

---

[1] LACIE is designed to meet USDA needs in areas where ground information is not readily available. To test the design in an area where comparison information is available, the U.S. (Great Plains) has been chosen. LACIE _is_ _not_ designed to improve the accuracy of U.S. crop reports.

1.2 BACKGROUND

The need for crop inventory information was stated[2] by the U.S. Department of Agriculture (USDA) as follows:

> "To permit rational decisions in areas such as production, marketing, transportation, and international trade, we must have up-to-date, accurate information on world food supplies and world food needs. The Department of Agriculture has been assigned the responsibility for collecting and reporting crop production information to the public."

In anticipation of helping to fulfill information needs such as stated above, the remote sensing community has for several years been developing a key part of a new technology for conducting large-scale crop inventories.

Some of the major events in the development and application of this technology were as follows:

Late 1950's	Surveys of agricultural terrain by black and white aerial photography using camouflage detection film (reflective infrared)
Early 1960's	Development of airborne multispectral scanners and large-scale digital-processing techniques

---

[2] From a presentation by Clayton K. Yeutter, Assistant Secretary for International Affairs and Commodity Programs, U.S. Dept. of Agriculture, to the Committee on Science and Technology, U.S. House of Representatives February 4, 1975.

1966	First computer-aided classification of wheat and other crops using airborne multispectral scanner data
1969	Apollo multiband camera experiment (S-065) simulating Landsat spectral bands. First computer-aided classification of wheat and other crops using satellite data
1971	Corn Blight Watch Experiment, first large area agricultural effort; used both image analysis and computer-aided analysis of airborne multispectral scanner data
1972	Landsat 1 launched; the start of many agriculturally-oriented investigations by Landsat scientific investigators, including several by representatives of the USDA and NASA and one joint project on crop identification

There had been acceptable progress in the development of techniques for the analysis of satellite-acquired multispectral data for the purpose of indentification and measurement of wheat areas. This capability to identify and measure wheat area provided, however, only one component for the estimation of wheat production. For USDA crop-reporting purposes, production (i.e., area in wheat multiplied by yield for that area) is the quantity of primary interest. Although there is an expectation that satellite multispectral observations will contribute to yield determination at some future date, this technology was not sufficiently developed to be included in the LACIE mainstream program. An alternate approach, however, using meteorological data (from ground stations and/or satellites) in yield models was in the course of development and was considered the most promising for supporting initial large-scale demonstrations.

Interest in pursuing inventory techniques was intensified by grain-production shortfalls in some areas of the world in 1972 and 1973 and by an increase in consumption during those years. This interest spurred planning activity in NASA, USDA, and NOAA, and the time was judged appropriate for a large-scale experiment to validate the technology as applied to a crop-inventory system. This technology had been previously tested only in local situations and with very limited amounts of data. Wheat was chosen as the crop for the initial experiment, and a preliminary project plan was developed in the fall of 1973.

An interagency Memorandum of Understanding (MOU) was drafted and detailed planning was carried out through the summer of 1974 with coordination among the three agencies. The general shape of the experiment was essentially defined by the middle of 1974 and all agencies began staffing the activity by the fall of 1974. An overall schedule for the project was approved in early November 1974.

The activity was announced November 6, 1974, and was described briefly by Secretary of State Kissinger at the World Food Conference in November 1974[3] as follows:

> "Our space, agriculture, and weather agencies will test advanced satellite techniques for surveying and forecasting important food crops. We will begin in North America and then broaden the project to other parts of the world. To supplement the World Meteorology Organization (WMO) on climate, we have begun our own analysis

---

[3]From a speech by Henry F. Kissinger, Secretary of State of the United States of America, in Rome, Italy, November 4, 1974.

of the relationship between climate patterns and crop yields over a statistically significant period. This is a promising and potentially vital contribution to rational planning of global production."

1.3 TECHNICAL DESCRIPTION

The objective of the LACIE is to estimate <u>production</u> of wheat on a country-by-country basis. To estimate wheat production on a country basis, the country is subdivided into subareas called strata, where yield (quintal/hectare or bushel/acre) and the prevalence of wheat planted are rather uniform. Yield and the areal extent of wheat within each strata are determined by independent methods and then multiplied together to obtain wheat production (quintals or bushels) for the stratum. The production estimates in each stratum are then added to obtain production at other geographic levels. In addition, area and yield are estimated for each stratum and aggregated to determine wheat area and yield at regional and country levels.

Area is derived by classification and mensuration of Landsat Multispectral Scanner (MSS) data acquired on a sampling of about 2 percent of the agricultural area in all regions where wheat is a major crop. Maximum use is made of computer-aided analysis to provide the most timely estimates possible.

Yield is estimated from statistical models which relate crop yield to local meteorological conditions, notably precipitation and temperature. Initially, these data are being obtained from the World Meteorological Network of ground stations. As the experiment progresses, use of supplemental meteorological data from NOAA environmental satellites is planned.

The project has involved the assembly of a crop-inventory system from available components designed for Research and Development (R&D). That is, the system is intended to test the functions necessary for crop inventory not to provide a streamlined, cost-effective operational tool. The intent is to utilize the experience gained to support, as a concurrent effort, the design of a user-oriented operational system and the prediction of the performance and cost of such a user system.

LACIE will extend over three global crop seasons, each of which is considered a LACIE phase. The early phases will concentrate primarily on the most important wheat-growing region of the U.S., the hard red wheat region in the U.S. Great Plains. This region comprises 9 states[4] which account for, typically, 90 percent of the hard red wheat and 75 percent of the total U.S. wheat. Then the experiment will be extended to include the major wheat producing regions of the world. These three phases overlap because they are based upon global crop-growing seasons. The first phase — covered in this report — began in November 1974 and was devoted primarily to the evaluation of the ability to locate, identify, and estimate the area of wheat in the Great Plains of the U.S. Data from the USDA Statistical Reporting Service were used as a reference from which to determine the accuracy of LACIE performance. Also during this phase, development and feasibility testing of wheat yield models was conducted. In Phase II, the major area of coverage remains the U.S. Great Plains; however, Canada will be included, and selected regions outside North America will be analyzed. Phase II extends from

---

[4]Texas, Oklahoma, Kansas, Nebraska, Colorado, North Dakota, South Dakota, Montana, and Minnesota.

October 1975 through April 1977 and involves an integrated test of the crop identification and area estimation capability along with use of the yield models to predict wheat production in the regions being studied. In Phase III, the LACIE capability should be able to support the estimation of wheat area, yield, and production in several countries, should such a scope be decided upon by the participating agencies. The current LACIE schedule is shown in figure 1-1.

ORIGINAL PAGE IS
OF POOR QUALITY

LACIE SCHEDULE LEVEL 1

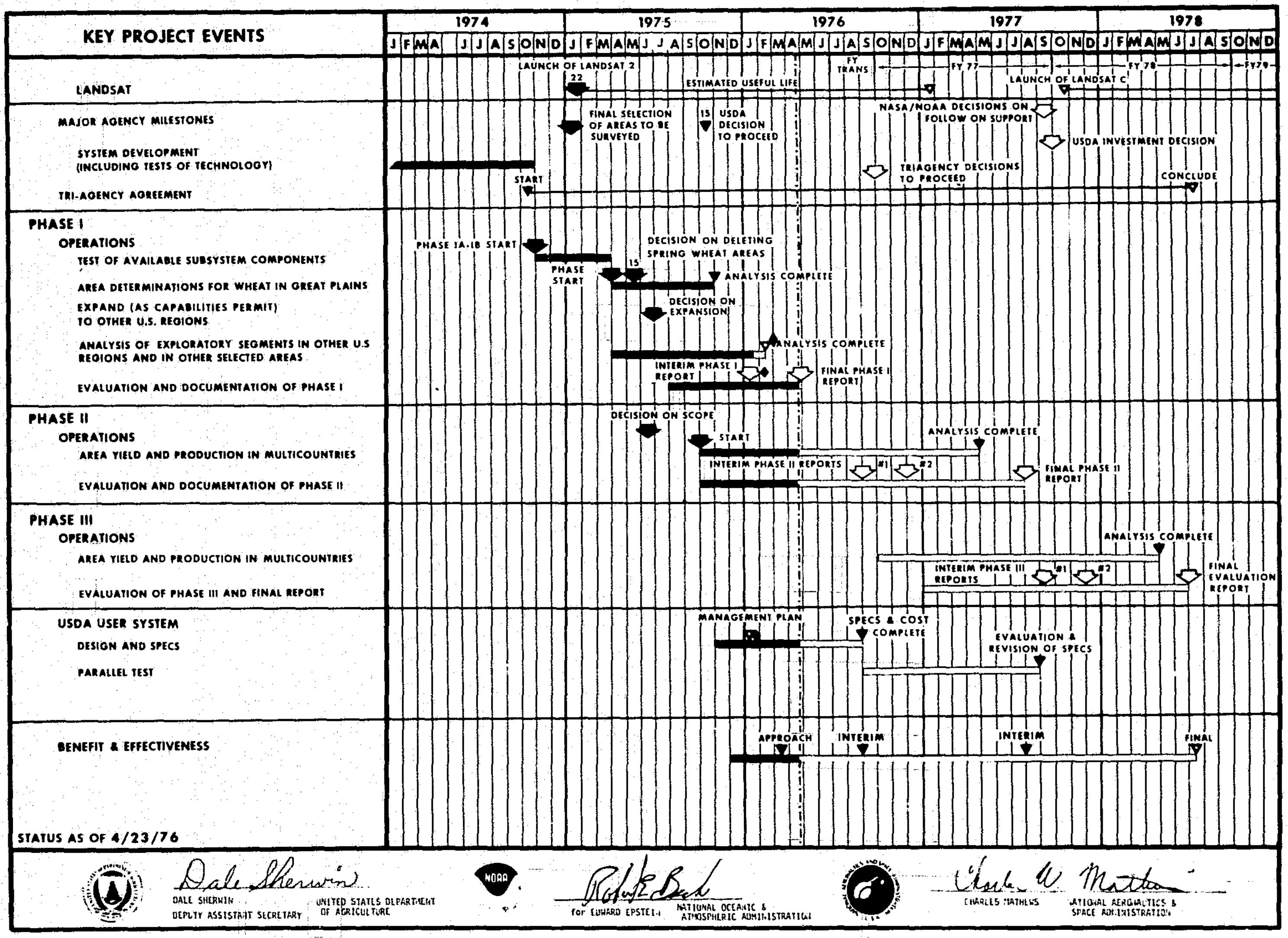


Figure 1-1.-LACIE Schedule Level 1 as of April 23, 1976.

SECTION 2.0

EVALUATION OVERVIEW OF PHASE I

2.1 GENERAL

Phase I of LACIE was a period of bringing system components into operation and testing their ability to meet experiment goals. Area estimation was performed in a quasi-operational mode, yield and production estimation in a feasibility test mode. Performance during Phase I of LACIE was very encouraging and Table 2-I summarizes Phase I goals and accomplishments.

An overall experiment design was completed (hardware, software, sample design, etc.) to support all three phases of LACIE and the Phase I system was exercised successfully. The initial quasi-operational system for area estimation was implemented and began operation on schedule. Yield and production estimates during Phase I were made throughout the phase but in a test and evaluation mode. Reports on area for the U.S. Great Plains were prepared monthly throughout the growing season. A single summary report on each of yield and production was developed at the end of the phase.

The accuracy performance of the LACIE estimates, based on a number of tests in the U.S. Great Plains, is considered marginally satisfactory in consideration of the 90/90 "at-harvest" criterion for wheat production estimation. This criterion specifies that at-harvest production estimates at a country level be 90 percent accurate 9 years out of 10 or 90 percent of the time.

TABLE 2-I.- PHASE I GOALS AND ACCOMPLISHMENTS

Goals	Accomplishments
Develop a system to test the components of the LACIE technology	An overall experiment design was completed (hardware, software, sample design, etc.) to support all three phases and the Phase I system was exercised successfully.
Conduct tests of the area-estimation capability over selected area within the U.S. Great Plains (the "Yardstick" region)	Tests successfully conducted for the nine states selected (the U.S. Great Plains).
Evaluate the feasibility of wheat classification over representative foreign locations for Phase II and Phase III	Tests conducted over segments in all LACIE countries. Experienced difficulties in some countries with small fields and with cloud cover in some cases. In other cases classification could be easier due to large fields and more uniform agriculture than in U.S.
Conduct feasibility tests of the yield and production estimation capability	Yield models for U.S. Great Plains checked historically over a 10-year period, production tested for 1975. Basic approach is adequate. Some improvements will be required.
Evaluate performance for accuracy, timeliness, and utility	Accuracy of results assessed by USDA as generally satisfactory. Timeliness and utility to be evaluated during Phase II.
Modify the technology as required for Phase II	Area-estimation technology revised and yardstick area reprocessed; areas for yield model improvement identified and some improvements implemented. Phase II initiated as planned.
Conduct parallel and supportive research, test and evaluation to investigate improved approaches	Phase I program produced several improvements to technology approach. These are being incorporated into Phase II and Phase III.
Implement the additional components of the system required to support quasi-operational yield and production estimates in Phase II.	Components were successfully implemented and are being exercised in Phase II.

Tests were also conducted over segments in all LACIE countries planned for Phases II and III. The results of this testing showed some regions for which area and yield estimation will be more difficult than in the U.S., the main factors being small field sizes, increased cloud cover, and poorer historic data. In other cases, however, area estimation appears easier as a result of larger field sizes and more uniform agriculture in regions such as the USSR.

As a result of Phase I experience, several problems were uncovered in the technology. The LACIE research, test, and evaluation program produced several improved technology approaches which were or are being implemented for Phases II and III.

2.2 AREA ESTIMATION

After correction of significant implementation problems in the initial quasi-operational area estimation system, the resulting wheat area estimation at harvest, based on its performance quantified over the U.S. Great Plains, was deemed marginally satisfactory in consideration of the 90/90 at-harvest criterion for wheat production estimation. The area estimation system shows a tendence to underestimate when compared to the SRS estimates. The LACIE Great Plains area estimate was approximately 46,000,000 acres compared to the SRS[1] estimate of approximately 51,000,000 acres, or about 10 percent below the SRS figure. Analyses show this difference to be statistically significant.

---

[1] USDA/SRS year-end estimates (December 1975).

A significant contribution to this underestimate is believed to be a sampling problem in North Dakota. An improved allocation of samples on the basis of a better partitioning of agricultural lands into more homogeneous strata is expected to reduce any bias to a tolerable level. The use of full-frame Landsat imagery is critical to defining adequate strata to avoid such sampling error; this improved sample allocation is currently planned to be tested in Phase III. The coefficient of variation (c.v.) computed for the LACIE area estimator, when projected to the U.S. national level, is about 5.0 percent, slightly above the 4.25 percent required if production estimates are to meet the 90/90 criterion. Because data loss due to cloud cover and early implementation problems resulted in a reduction in the number of LACIE sample segments used (of 411 allocated, 380 were acquired and 272 were used), this random error component can very likely be reduced to or below the acceptable limit of 4.25 percent by the improvements implemented and planned for Phases II and III.

The results of this quasi-operational test for area were further examined in the Phase I production feasibility test where the LACIE area estimates were combined with LACIE Yield estimates and resulting production estimates evaluated. This production estimate satisfied the 90/90 criterion and indicated the basic compatibility of the LACIE area and yield estimators.

Accuracy was also examined for selected sample segments and the results indicate that the Landsat data and the classification technology can estimate the small grains (i.e., wheat and closely associated small grains) area within a sample segment accurately and reliably enough to meet the LACIE goals. The LACIE estimates in the segments agree well with independent

estimates from ground and aircraft observations. In North Dakota, where 20 such sites were examined, no significant difference was detected between the LACIE and ground observations over the sample segments. The estimated c.v. of the random classification error was "acceptably" small. These analyses confirmed that bias introduced by various factors such as Landsat spatial resolution, lack of spectral resolution, classifier (analyst interpreter) bias and repeatability, etc., is not excessive, in terms of the required performance criterion.

Results of these tests did indicate a difficulty in differentiating wheat from other closely related small grains. However, wheat area estimates were obtained through the reduction of the small grain area estimates in accordance with the historic prevalence of these crops.

There are some indications that in regions that have marginal wheat production, small fields, or large amounts of confusion crops; wheat identification may be more difficult than in higher producing areas. LACIE plans to monitor these situations closely during Phases II and III.

The several approaches taken to estimate sample error indicate that for the U.S. Great Plains it is acceptably small given all the allocated segments. Loss of acquisitions from cloud cover was a problem in Phase I; however, tests conducted to date indicate that error arising from this loss is probably random in nature with no significant bias being introduced.

In North Dakota, a significant underestimate of the wheat area was observed. Further analyses indicate the major problem is

with the sample placement as opposed to the classification analysis. Indicated solutions are the allocation of additional samples or improved stratification to reduce agricultural area variability or both.

2.3 YIELD ESTIMATION

The Phase I testing of the yield models[2] indicated that the models can be expected to support the 90/90 criterion in regions having characteristics similar (in geography and agriculture) to the states in the yardstick region. It is recognized, however, that the models may not perform as well in foreign areas where historical record data are lacking or nonexistent.

In a test of the yield models over the years 1965 to 1975, the c.v. of the yield estimates was on the order of 2 percent at the national level, lower than the 4.25 percent required. When combined with SRS area estimates in these same years, the yield estimates would not satisfy the 90/90 criterion for production given errors of equal magnitude in the area estimates. However, it was noted that a source of the yield estimation error was the form of the model which resulted in unrealistically high or low yield estimates for extremely high or low values of the temperature or precipitation. An improved model has been developed. Tests of this improved model indicate that it will significantly improve estimates and meet the criterion.

---

[2]These models will be incorporated into the LACIE quasi-operational system in Phase II.

2.4 PRODUCTION ESTIMATION

When the LACIE area estimates and the LACIE yield estimates are combined, the resulting production estimates satisfy the 90/90 criterion. In the Great Plains, the LACIE production estimate was 8.8 percent below the SRS final estimate for the same region.[3] The c.v. of the LACIE production estimate was 5.3 percent at the Great Plains level and 4.2 percent when projected to the national level. This is within the acceptable tolerance of 6 percent for an unbiased estimation. Because the difference between the SRS and LACIE estimate at the Great Plains level is not significant (i.e., could likely be a random fluctuation in this statistical quantity), the estimator can be judged to satisfy the 90/90 criterion because the c.v. is less than the 6 percent required. The largest regional problem observed is once again in North Dakota where production is significantly underestimated because of the area estimation discussed earlier.

2.5 RATE OF ANALYSIS OF LANDSAT DATA

The performance goal for the rate of analysis of Landsat data was to be able to process between 15 and 20 segments per working day and to complete a segment in a timely fashion such that, in a truly production operation, data from the satellite would be analyzed and available for aggregation within 14 days of acquisition. By the end of Phase I, the volume of data being analyzed was meeting Phase I goals (fig. 2-1). It was determined that actual demonstration of a 14-day turnaround

---

[3]This is for the original yield model. When the revised model is used the corresponding difference is -5.6 percent (see Appendix A).

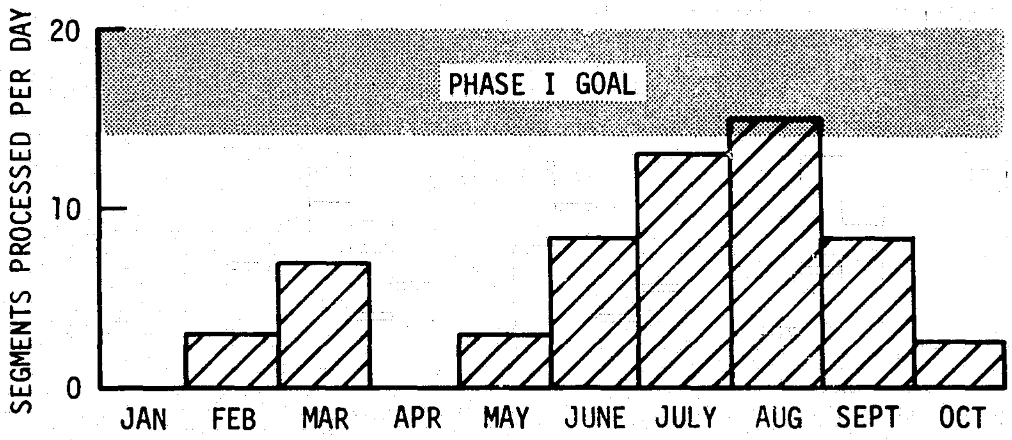


Figure 2-1.- Rate of processing Landsat data.

was not necessary if it could be shown that this turnaround could have been attained in a three-shift production operation. During Phase I, there was a number of conditions typical of the start of an operation which led to backlogging of data; hence, the turnaround time was long in comparison with the goal. When actual time in process was considered, then the turnaround time was 30 to 31 days. This should be compared to a target time of 29 days (which corresponds to the 14-day goal when adjustments are made for the number of shifts employed). There are known areas where further improvement can be realized; these have been analyzed and improvements are being incorporated.

2.6 SUMMARY AND OPEN ISSUES

There is considerable confidence from the Phase I results that LACIE will meet its Phase II and III accuracy goals in the U.S. Because some degradation in performance is to be expected when expanding to some foreign areas, it is vital to reach or exceed the accuracy goals in the yardstick area. In addition, the following significant open issues exist in area estimation:

A. Technical problems are involved in distinguishing between wheat and other small grains. Implicit in these problems is the questions of how important is this capability. This is being addressed in Phase II. Two approaches are being evaluated: (1) making an estimate for small grains as a class, and (2) ratioing techniques utilizing historical data on the prevalence of wheat to develop an estimate for wheat from the small grains estimate.

B. Signature extension — technology available at the start of Phase I was inadequate and was removed from use. Substantial research efforts have been directed toward the various technical aspects of this problem during Phase I. Promising approaches are being tested in Phase II for incorporation in Phase III.

C. Multitemporal analysis techniques — technical problems precluded the full use of these techniques early in Phase I; however, the problems were remedied, and successful use of multitemporal analysis was made in Phase I.

D. Partitioning of the LACIE survey regions into areas of similar agrophysical properties needs to be greatly improved. It remains an open question as to how effectively data such as soils maps, climatology, topographic data, and Landsat full-frame imagery can be used to develop improved partitions. Such partitions are important for improvements in sampling, use of ancillary data, development of interpreter keys for Landsat data analysis, signature extension, and yield modeling.

In the yield estimation activity, it is clear that improved models are both desirable and possible. Approaches to relate the models more closely to actual plant growth conditions are underway and refined models will be tested in Phase III.

In conclusion, Phase I was a successful step in LACIE, considering the complexity of the undertaking. No fundamental changes were required in the experiment approach or schedule. The technological problems and startup difficulties encountered during Phase I were generally anticipated. It is considered

that the project staff has the required skills and motivation to resolve those issues still open and complete Phases II and III successfully.

SECTION 3.0

SUMMARY OF PHASE I TECHNICAL ACTIVITY

3.1 OBJECTIVES

A detailed statement of the experiment objectives is given in the LACIE Project Plan. Briefly, the major goals to be accomplished by the end of Phase I were the following:

A. Select the most promising technology components to (1) identify wheat and estimate its area, (2) estimate yield, and (3) estimate production.

B. Complete an overall experiment design (hardware, software, sample design) required to support all three phases.

C. Implement that part of the analysis system required to estimate wheat area over most of the hard red wheat region of the United States (the Great Plains).

D. Develop procedures for handling and analyzing large quantities of data required in LACIE to meet the planned expansion into foreign areas.

E. Select and train personnel from the three participating agencies to implement, operate, and evaluate the LACIE system.

F. Exercise the system in a quasi-operational manner and estimate wheat area over the U.S. hard red wheat region and

evaluate[1] the results, both against established performance criteria for at-harvest estimates and to determine how accurately early season estimates can be made.

G. Test selected methods for estimating wheat yield and production prior to implementation of this capability for Phase II.

H. Conduct parallel and supportive research, test, and evaluation to investigate improved approaches.

I. Conduct initial analyses over selected foreign areas and areas in the United States outside the Great Plains yardstick area prior to expansion in Phase II.

J. Develop and implement evaluation plans for subsequent phases (II and III).

K. Implement the additional components of the system required to support making quasi-operational yield and production estimates in Phase II.

---

[1] The "90/90" criterion was selected as a goal. This means 90 percent accurate, at-harvest, by the end of the experiment (in comparison with the true value) 90 percent of the time. As a practical matter, the best available yardstick value is used for comparison. In the U.S., these are Statistical Reporting Service (SRS) results; while no specific accuracy goal exists for estimates prior to harvest, reports are issued on a regular basis.

3.2 ACTIVITIES AND ACHIEVEMENTS

The activities and achievements described in this section represent the highlights of Phase I in the light of which the evaluation in section 4.0 is made. The major achievements and results to date are the following:

3.2.1 Area Estimation

A. An existing data system at the Goddard Space Flight Center (GSFC) was modified with both software and hardware additions to screen LACIE segments from the overall digital data acquired by Landsat, conduct a temporal registration, format the data, and transmit them to the Johnson Space Center (JSC). Data acquisition and processing started as scheduled in November 1974.

B. An existing data analysis system at JSC was modified to provide an interim LACIE system to analyze LACIE-formatted data in the early part of Phase I (November 1974 through March 1975), and analysis was started as scheduled in November 1974.

C. The first data analysis system (LACIE 2 Automatic Data Processing (ADP) system) responsive to the LACIE requirements for multispectral data classification was delivered in April 1975 on schedule. It was put into operation smoothly and used for analysis of the bulk of the Phase I data.

D. Landsat 1 data over Kansas from the 1973-74 crop year were edited retrospectively from archived data and transmitted to JSC in LACIE format. These data were analyzed during the period from November 1974 through January 1975, using the interim LACIE data system and interim classification procedures.

The data sets were all for a single date; i.e., no multi-temporal analysis was employed. Comparisons were made with the USDA statistical reporting Service (SRS) state estimate and with ground truth data acquired by ASCS on intensive test sites. A relative difference from the SRS data of -3 percent was noted with a coefficient of variation of 6 percent.

E. A sampling strategy was developed to acquire Landsat data for the yardstick area (U.S. Great Plains) and for foreign exploratory areas. To provide data for a full crop year (1974-1975) of winter wheat activity in the U.S. Great Plains, both Landsat 1 and Landsat 2 were required. Landsat 1 data were retrieved from archives for analysis of fall acquisitions of winter wheat segments. These data were analyzed using the interim LACIE data system during the period January-March 1975.

F. Landsat 2 data acquisition was initiated shortly after launch (January 1975) as crop development proceeded (i.e., as bio-windows opened up).

G. The LACIE system for analysis of Landsat acquired data segments operated at increasing throughput rates and, toward the end of Phase I, reached a rate of just over 15 segments per day. This compares favorably with the planned peak delivery rate in the range of 15 to 20 segments per day. Initially, the throughput rates for these data were limited by a multitude of operational and logistic problems, most of which were subsequently resolved.

H. Models for making seasonal adjustments to the crop calendars for the U.S. Great Plains were implemented at the NOAA Center

for Climatic and Environmental Assessment (CCEA) and commenced operation in April 1975 at CCEA with results transmitted to the JSC.

I. Provisions for gathering meteorological data for use by classification analysts were implemented by NOAA. These data were extracted from various ground sources such as the WMO network and compiled by NOAA staff at JSC. This activity commenced in April 1975. During Phase I, the utilization of NOAA satellite imagery was also initiated to increase the information flow to the classification analysts. This use was primarily to explore, from the satellite imagery, the cause and extent of anomalous situations.

J. An interim capability to aggregate segment results to provide area estimates was implemented in April 1975. Area aggregations for the U.S. Great Plains were completed from April through August 1975.

K. The initial analysis of a major portion of the Phase I data for the U.S. Great Plains was essentially completed by late July 1975. The results showed area estimates substantially higher than the SRS results for most states. Results were better for winter wheat states than for spring and mixed spring and winter wheat states and, on a segment basis, better for areas in which wheat is common than for areas in which it is sparse.

L. The high estimates were unsatisfactory and prompted the initiation of a close review of the area-estimation technology in early August. This review had broad participation from the remote sensing community and confirmed that

incorrectly implemented procedures existed in the original analysis approach. For example, because of the great importance of an early estimate, an attempt was made to arrive at an estimate using fall data which showed little wheat emerged. Areas of seed bed preparation were accordingly classified as "potential wheat" and included in area aggregations. Since seed bed preparations are made for other reasons, this led to a significant overestimate.

M. The identified problem areas led to a revision of the analysis procedures and to the initiation of an effort to reanalyze the U.S. Great Plains regions in order to evaluate the modified procedures.

N. The rework effort was completed in November 1975, and gave area-estimation results which indicated that, at a national level, estimates would be within 10 percent of the SRS results. A significant discrepancy in North Dakota estimates was identified.

O. During Phase I, a total of 693 segments were studied. In the U.S. Great Plains, an average of 2.3 Landsat images was acquired for each segment, following the practice of utilizing the first good acquisition in each of the four biowindows. Cloud-cover conditions accounted for almost all the missed data.

P. Area, yield, and production aggregations (Appendix A) were conducted over the U.S. Great Plains (Texas, Oklahoma, Kansas, Nebraska, Colorado, North Dakota, South Dakota, Montana, and Minnesota). Results indicate the relative difference (bias) of the LACIE North Dakota area estimate to be the major component of the relative difference in the production estimate.

Q. Classification tests were conducted on 207 exploratory segments distributed among the other LACIE countries.

R. Accuracy assessment activities were initiated in July 1975 and tests were conducted using segments where ground truth data were available (from 29 Intensive Test Sites (ITS) and from 28 "blind sites" where data were gathered after the analysis). Some 340 special analyses were conducted to support the accuracy assessment. Basically these were special tests to study the source and nature of classification errors. In this accuracy assessment effort, state-level results were studied to understand the effect of the component parts of the error; for example, sample error versus classification error and the interaction between classification and sampling errors particularly on the area aggregations (Appendix C). The results from these tests indicate:

1. In North Dakota, where the best estimates of classification error are available, the observed relative difference does not appear to result from classification error (Appendix C). Tests in Montana also tend to confirm adequacy of classification.

2. In all states but Nebraska, classification error is about equal to the relatively small sampling error.

3. In Nebraska, classification error is much larger, indicating problems with confusion crops (Table C-V, Appendix C.)

4. The random component of sampling error appears to be nominal in the four states examined.

5. In North Dakota, where ground data for 20 segments were compared to SRS county estimates, a difference was observed which would account for the negative relative difference in North Dakota (Table C-II, Appendix C).

6. An estimated random sample error component of 13 percent for North Dakota would not account for this relative difference (Appendix C).

7. In the U.S. Great Plains, SRS county estimates were substituted for LACIE segment estimates in an aggregation test to ascertain if any bias due to cloud cover was present. Overall no bias could be detected except for Colorado.

S. Preliminary results from the area estimation accuracy assessment indicate the major components in the relative difference (bias) of the LACIE North Dakota area estimate to be sampling error (bias) resulting largely from allocation of some samples to nonagricultural areas.

3.2.2 Yield Estimation

A. Models to project wheat yield for regions within the U.S. Great Plains (the "yardstick area") were developed and implemented at NOAA/CCEA. Test runs on a regular basis were commenced in April 1975.

B. A capability to operate yield models at the NOAA/Page Facility in Washington, D.C., was demonstrated in June 1975.

C. Tests of the U.S. Great Plains yield models for the 1974-75 crop year show a negligible relative difference (less than 1 percent) for the total region when compared to SRS results. The coefficient of variation was also small (3.5 percent). If this result was typical for all years, the yield models would support the project accuracy goals.

D. Tests of the yield models for the U.S. Great Plains were conducted retrospectively for the period from 1965 to 1974. The results, when compared to SRS data, indicated that the models would fall slightly short of meeting the 90/90 criterion. The models were improved retrospectively and the tests were rerun. It now appears that the yield estimates in the U.S. Great Plains will support the accuracy goals (see Appendix B).

3.2.3 Production Estimation

A. The feasibility of estimating production was tested by combining LACIE area estimates and LACIE yield projections. When compared to SRS results, the LACIE at-harvest estimate for the region of the nine Great Plains states indicated a relative difference of approximately 8.8 percent with the original yield models and -5.6 percent with the revised models. The coefficient of variation is 5.3 percent.

3.3 PROBLEMS

There were technical and nontechnical problems which arose during Phase I. Those described in this section are the major ones

which were encountered. Some have been resolved and others remain issues. All open items are being pursued as part of Phase II activity.

This section (3.3) is intended to give brief descriptions in one location of the major problems encountered. These descriptions should be read in conjunction with Section 4.0 and Appendices A, B, and C to gain a valid assessment of the significance of these problems.

A. The interpretation of the Landsat data themselves for training the classifier was generally successful except that it was consistently difficult to discriminate between wheat and other small grains (oats, barley, rye). This is still an open issue.

   However, two approaches are being pursued. One is to make an estimate for small grains as a class. This is a useful estimate in and of itself. A second approach is to apportion the total area estimated to be in small grains into wheat and other according to the historic prevalence of wheat in each locality. This "ratioing" technique is expected to give a valid estimate for wheat and initiate the construction of a historical data base of consistent estimates utilizing Landsat input.

B. A basic element intended in the LACIE classification approach was the use of multitemporal analysis; i.e., using the data from multiple Landsat passes in the analysis. The initial implementations which were unsuccessful were successfully corrected and limited use was made of selected multitemporal data sets in the rework of the U.S. Great Plains. Use of multitemporal analysis will continue during Phase II.

C. Another major element in the LACIE technical approach is the use of signature extension to amplify the training knowledge

from one or more segments to one or more neighboring segments of similar characteristics. An initial implementation was utilized during the first several months of Phase I. The results, however, were not satisfactory, and signature extension appeared to work in only about 20 percent of the cases. The LACIE Research, Test, and Evaluation (RT&E) activity has recently produced an improved signature extension technology, and activity is planned for Phase II to advance and test signature extension capabilities so that this technology can be utilized in Phase III.

D. Historical agricultural data (growth stages, yield, etc.) were often not available in consistent format or at the right level of detail for full utilization. This hampered the development of yield models, adjustable crop calendars, and data packages to aid in classification of Landsat data. Adequate data to support activities in the U.S. Great Plains, the yardstick region where analytical techniques are calibrated, are expected for Phase II. All the historical data that may be desired may not be available in other parts of the world. This is being taken into consideration, and analysis techniques are being structured accordingly.

E. Crop calendars incorporating seasonal adjustments for winter wheat in the U.S. Great Plains were not available early in Phase I, and data for the first (fall biowindow) acquisition were therefore timed according to average calendars. The actual situation for winter wheat in the fall of 1974 was such that planting and wheat growth were substantially delayed. Thus, data gathered at a time when wheat would normally have emerged showed only bare soil. This is not expected to be a problem in Phase II since data from all Landsat passes are now

being acquired and examined. This allows a determination to be made as to whether or not a particular extent of emergence has occurred and only when the crop is sufficiently advanced will analysis be continued.

F. Because an estimate of wheat production early in the crop year is considered especially valuable, it has been a project concern to produce estimates as early as possible. During Phase I, an attempt was made to arrive at an area estimate using fall data which (as stated in paragraph E above) showed little wheat emerged. The approach was to classify areas of seed bed preparation or bare soil as "potential wheat." However, fall plowing and seed bed preparation are conducted in many areas for purposes other than planting wheat, and thus LACIE gave a higher area estimate (by a factor of 2 or more) than SRS data.

G. The high area estimates noted early in the season persisted through the crop year as a result of retaining a substantial amount of the early biostage segments for which "potential wheat" was estimated. These estimates were used for segments which had no later acquisitions. The estimates were some 40 percent high for the U.S. Great Plains. A number of possibilities to improve the estimates were determined in detail by participants during and after the Area Estimation Technology Review conducted in August 1975.

It is felt that the major causes of the high estimates in addition to the example described in section 3.3 (F) were (1) cases in which wheat could not be separated from small grains and other crops and (2) cases in which an ambiguous classification would be arrived at, such as results for three

overlapping classes - "winter wheat," "spring wheat," and "wheat." This situation has been resolved by a consistent and mutually exclusive set of class and subclass definitions plus a procedure for apportioning gross categories like "small grains" among the specific classes allowable.

H. The operations for analysis of Landsat data during Phase I were characterized by a number of "start up" situations peculiar to the particular implementation of the experiment and by the high level of rework required as procedures were refined. This led to a median processing time of 40 days from acquisition until completion of the analysis. It is deduced that a 14-day turnaround could be attained in a three-shift production operation.

I. As a result of the general magnitude of the LACIE task and, in part, because of the rescoping to meet budget, an automated status and tracking system was never implemented during Phase I, and tracking was done manually. A good picture of just where segment processing stood was not always available, nor could progress be statused by geographic location, biowindow, etc. An improved status and tracking system is now available, and the problems experienced are in no way basic to the LACIE approach.

J. Certain problems were found in the sampling. One is in the incorrect placement of samples in nonagricultural areas due to lack of proper delineation of such regions (see 3.2.1 (R)). Another problem concerns the assumption that counties are relatively homogenous. Actual experience has not supported this. Such effects have yet to be verified and quantified, but they may require that a new set of segments be defined for Phase

III in selected areas. Landsat data coupled with topography, soil families, and climatic data provide the basis for the delineation of areas to be sampled, and hence any improvements of this type deemed to be desirable will be carried out for both foreign and domestic regions.

SECTION 4.0

EVALUATION OF PHASE I TECHNICAL ACTIVITY

4.1 ATTAINMENT OF OBJECTIVES

With respect to the major objectives set forth in Section 3.1, the interim evaluation is described in the following paragraphs.

4.1.1 General

An evaluation was made of a number of general items not tied to any one aspect of the experiment. In particular, the following should be noted.

A. The data acquisition and analysis system that was planned (including various elements at different locations) was developed in a timely manner and generally performed well. Further, it was upgraded in significant ways during the course of Phase I. The mechanical aspects of the design were satisfactory in being able to carry out all the planned functions and produce the required products. There were three significant shortcomings in the overall LACIE system. The most serious was the relatively long time it took to get analysis products (film, computer runs, etc.) back to the analysts as a segment moved from one stage of processing to another. A second problem was the absence of an automated status and tracking system and a manual workaround was required. The third was that only a relatively simple aggregation system was available and this also required cumbersome workarounds, such as building a separate data base for each aggregation. All three of these shortcomings are being corrected for Phase II.

B. The LACIE system included personnel and procedures as well as software and hardware. Staff members were hired and trained to support analysis activity as required. Procedures were developed for use in analysis of LACIE data, but documentation was not as complete as planned for Phase II. Shortcomings were identified and corrected.

C. Modifications to the technology were made at many points in the LACIE system throughout Phase I. The system, including both physical and human elements, has proven to be adaptable to change.

D. The location of the 5x6 nautical mile (n.mi.) segments used in the LACIE analysis of acreage is typically within ±1 n.mi. of the target location compared with a specified ±3 n.mi. This is for the first acquisition of data for that segment. It has been possible to register subsequent acquisitions to the first with an accuracy of about 80 meters.

4.1.2 Area Estimation

A. Two test results from Phase I pertain to area estimation capability:

1. A very limited early investigation in Kansas, a winter wheat region, for 1973-1974 (para. 3.2.1 (D)) would indicate, if results were projected to the national level, that the 90/90 performance goal for production would be met.[1]

---

[1]This assumes an equal distribution of error between area and yield and that the bias is within +5 percent.

2. The major effort over the U.S. Great Plains indicates the following:

   a. The area estimation results are marginally acceptable in supporting the 90/90 production estimation criterion. The accuracy for winter wheat in the southern U.S. Great Plains appears better than for spring and mixed spring and winter wheat regions in the northern Great Plains.

   b. A study of state-by-state variations indicates that a major source of error in the estimate of spring small grain area in the spring wheat states is sample error in North Dakota. This error is thought to result from heterogeneities in agriculture within the LACIE sample strata (counties). In addition, spring wheat cannot be adequately distinguished from spring small grains, although spring small grains can be distinguished quite adequately from other crops. For winter wheat, the major source of error appears to be classification error in marginal areas such as Nebraska, where confusion crops such as alfalfa are in abundance. Moderately large but tolerable sample error is also noted in the winter wheat states other than Kansas. The prognosis at the national level is that, given resolution of the problem causing the underestimation in North Dakota, LACIE area estimates should support the 90/90 criterion for accuracy of the production estimates.

c. A study of intensive test site data, where ground truth was available, gave a further indication that the classification procedure for developing area estimates from Landsat data was performing well. A test on 9 segments for which the proportion of wheat (or small grains) estimated by the LACIE classification procedure could be compared with the proportion from ground data, indicates a relative difference and a coefficient of variation well within the tolerable limits at a segment level to support the 90/90 criterion.

d. Two consistency tests show that the area estimation procedures are repeatable with respect to analyst performance. One test with 14 analysts each studying two sites showed no statistically significant difference with respect to analysts or to the biowindow within which the data was acquired. Another test with four analyst teams each studying nine sites showed no significant difference among the teams. Further, this test involved a rework of sites which had been processed originally through the normal data flow. No significant change was noted between the original and the reworked results.

B. Classification tests were conducted on exploratory segments over all seven LACIE countries outside the U.S. Of the exploratory segment acquisitions received at JSC, approximately one-half were classified and wheat proportions generated by CAMS. This was the same proportion experienced for all LACIE acquisitions and reflects the processing of the exploratory segments by CAMS with the normal Phase I procedures.

Examination of exploratory imagery obtained in Phase I showed that many of the segments were located in nonagricultural areas. This problem was referred to in paragraph 3.3 J. Agricultural-nonagricultural redefinition will be repeated for the areas in question during Phase II using Landsat imagery.

In the case of the USSR, Argentina, and Canada, the exploratory segments were considered to be representative of the countries' agriculture. The analysts' qualitative evaluation of classification tests is that the USSR is likely to be straightforward with large fields and homogeneous signatures. Canada is more difficult than the U.S. because of extensive strip/fallow cropping and a greater variety of competition crops.

India and those areas of China with small fields will be difficult, and it is not yet known what accuracies can be expected. For China, a new selection of exploratory segments in one province has been made for Phase II in hopes of gaining better experience by concentrating in one agricultural area.

Little experience was obtained in analysis of Landsat data acquired over Brazil, Argentina, or Canada because relatively few acquisitions were obtained. A problem experienced with processing of exploratory segments was that of inadequate or incomplete ancillary data (see paragraph 3.3D).

C. The adjustable crop calendar model works reasonably well (given good starting dates) and is almost always a significant improvement over the average crop calendar.

D. The area-estimation technology was tested throughout Phase I. Procedural changes were made and further tests conducted as the experiment proceeded. It now appears that the area-estimation technology will be adequate for LACIE.

E. Area-estimation accuracy is suffering, although not to an intolerable degree, from the lack of data lost to cloud cover. A preliminary indication is that excellent classification results can be obtained with data from the first and fourth biowindows plus either the second or third. Thus, an average data return of 2.3 acquisitions per segment is on the lean side. Steps to improve this situation are being explored.

F. See Appendix C for a more detailed treatment of accuracies obtained in area estimation.

4.1.3 Yield Estimation

A. The 1974-75 crop-year results in the U.S. Great Plains would indicate, if typical, that the yield models estimations are sufficiently accurate to meet the 90/90 production criterion.[2]

---

[2] Based on an estimate of the standard deviation projected to the national level and on the assumption that the production bias is within +5 percent.

B. The 10-year test indicates that the initial models missed the 90/90 criterion by a narrow margin. However, there were indications of where improvements were necessary, and some relatively straightforward measures were taken. The capability to project yield was improved and the improvement tested in the U.S. Great Plains. The evaluation is that this component of the technology will support LACIE goals for future phases of the experiment. However, further improvements to selected models are planned.

C. See Appendix B for a more detailed treatment of yield estimation accuracies.

4.1.4 Production Estimation

A. The capability of making production estimates at two levels of aggregation, the Crop Reporting District (CRD) and the state, was demonstrated, and this capability should, with some minor improvements support the remainder of the experiment. The area estimation and yield estimation accuracies can be improved to meet these production accuracy goals. The combination of the area and yield estimates to a production estimate will introduce no further error.

B. See Appendix A for a more detailed treatment of production estimation feasibility studies conducted.

4.2 TECHNOLOGY SUMMARY

4.2.1 General

A major goal of LACIE in general and of Phase I in particular was to validate, where possible, key elements of the technology for

crop inventory, and to identify areas in which the technology needed strengthening. To a large extent, both aims were accomplished.

4.2.2 Technology Validation

Major elements of the technology that are considered to be validated are a capability to:

A. Search Landsat data, edit a desired area, and conduct a temporal registration to 1 pixel.

B. Extract a preselected sample segment to within 1 n.mi. of its actual position.

C. Automatically screen data that exhibit much cloud cover without discarding good data.

D. Collect, periodically, multistage "ground truth data" within the U.S.

E. Provide large amounts of high-quality film products.

F. Employ very large scale mass storage and tape storage facility for electronic data and track updates, purges, and related activities.

G. Maintain files, logs, and distribution systems for manual control of physical data products.

H. Accurately select (locally), from Landsat data alone, training fields for use in computer classification of multispectral data (considered partially validated in view of the difficulty in separating wheat from other small grains).

I. Provide adequate weather data to interpreters/analysts to support identification of wheat.

J. Use single or multitemporal data sets for wheat classification by maximum-likelihood techniques.

K. Automatically process small fields of the type most common in North America (strip/fallow).

L. Acquire, process, and transmit necessary meteorological data from a worldwide network.

M. Develop and operate mathematical models to estimate the stage of crop development and to project yield.

N. Status and track a large amount of remote sensing and meteorological data and a wide array of internal and output data products.

4.2.3 Technical and Procedural Issues

Major elements of the technology and the procedures that require strengthening are the following:

A. Accuracy of area estimates

B. Accuracy of yield estimates

C. Ability to acquire and analyze data in a timely manner

D. Ability to partition study regions and to extend signatures from one segment to another segment within the partition

E. Incorporation of evapotranspiration and other weather-related variables within actual crop calendar periods (adjusted for current year weather) into yield models.

F. Applicability of adjustable crop calendar for wheat to various confusion crops

G. Accuracy and detailed local applicability of crop calendar starter models

H. Utilization of meteorological satellite data in crop calendar and yield model areas

I. Capability to provide effective quality control on data and analysis procedures

J. Capability to provide a specific scheduling of LACIE segments for processing

4.3 SUPPORTING RESEARCH PROGRAM

An important part of LACIE is a supporting research and test program. Substantial progress was made in a number of areas, some of which will contribute to LACIE during the life of the experiment. The most noteworthy items are the following:

A. Alternate yield-modeling approaches were developed and tested under contract. Their main advantage is a spatially more detailed meteorological input permitting expression of a more

directly cause and effect relationship, a feature that will be incorporated into later LACIE models.

B. An improved crop calendar and starter model for winter wheat was developed at Kansas State University. This will be incorporated into LACIE.

C. A field measurements program has been conducted at two "super sites" during Phase I. This program will provide, in addition to a field data set for LACIE use, a data set of enduring value for remote sensing research. Landsat, aircraft, helicopter spectrometer, and field spectrometer data were gathered as nearly simultaneously as possible. A third site has recently been added to provide a wider range of agricultural conditions and the locations now under study are Finney County, Kansas (winter wheat), Williams County, North Dakota (spring wheat), and Hand County, South Dakota (both winter and spring wheat).

D. An error model was developed under contract. This model is presently in use and will permit the simulation of the accuracy effects of changes to various input parameters.

E. Signature extension research was carried on at the Laboratory for Applications of Remote Sensing (LARS, Purdue University; the Environmental Research Institute of Michigan (ERIM), Ann Arbor, Michigan; Texas A&M University; University of Houston; University of California at Berkeley; and Kansas State University. This work continues with activity both in the project and in the research community. Although signature extension is still a major area of technical risk, it is believed

that LACIE has significantly focused and advanced the development of this area of technology and there is reasonable hope that a viable capability will exist by the end of the experiment.

In summary, substantial progress has been made in validating a crop-inventory system based on multispectral remote sensing and mathematical yield models. The activity in LACIE has provided the best demonstration to data that wheat can be identified and the area measured by satellite remote sensing.

SYMBOLS

c.v.	Coefficient of variation
$\overline{\text{c.v.}}$	Segment level coefficient of variation
N_t	Total nationally allocated samples
Subscripts:	
P	Production
A	Area
Y	Yield
C	Classification
S	Sampling

APPENDIX A

SUMMARY OF PRODUCTION ACCURACY ASSESSMENT

A1 ACCURACY ASSESSMENT METHODOLOGY

Phase I goals called for wheat area estimates in a quasi-operational mode and the yield and production estimates as part of the research, test, and evaluation program. This appendix discusses the results of the production feasibility study conducted on the Phase I LACIE estimates in an RT&E mode. These results are examined in terms of the LACIE accuracy goal of estimating wheat production at-harvest[1] for a country to within 10 percent of its true value in 9 of 10 years, referred to as the 90/90 criterion.

In principle, the evaluation of the LACIE production estimates against this criterion would require a comparison of the LACIE estimates to the "actual" production for a period of several years. This approach is obviously impractical to implement until several years of operational experience is obtained.

In practice, LACIE must estimate its performance parameters from data analysis experience acquired to date and draw inferences as to the performance of the technology if it were to be operated for a span of several years. These inferences can be viewed with confidence as long as the conditions under which they are likely to be valid are borne in mind. The ability to identify wheat, measure its areal extent, and estimate wheat yields

[1]It should be understood that LACIE does make production estimates throughout the growing season but the valid basis for comparison is the at-harvest estimate.

is dependent to some degree on the extant agricultural and meteorological conditions; thus, the performance will vary with these factors which will change from year to year. For example, the estimation of area and yield in unusual or episode years with large regions of severe drought or winterkill will certainly be more difficult than in normal years in which the response of the crop to its environment is better documented and understood.

In Phase I, the performance of the LACIE production, yield, and area estimators were evaluated and the magnitudes of their component errors estimated in the manner described generally below. These analyses were conducted through quantitative statistical comparisons to ground observations of wheat area and condition, historic data published by national reporting services and current year area, yield, and production estimates published by the Statistical Reporting Service (SRS) of the USDA. It is these latter data which are used as the "actual" or reference standard data at the state and national levels. While these SRS estimates are not exact, they are believed to be sufficiently accurate at the Great Plains level to serve as a reference standard for LACIE. At state levels and below, a significant part of the difference between LACIE and SRS estimates can be attributed to errors in the SRS figures.

To determine if the LACIE estimators of production were able to satisfy the 90/90 criterion discussed above, the performance data were used to examine the contention that "The LACIE production estimate for the U.S. is, with a probability of at least 90 percent, to within ±10 percent of the 'actual' production estimate for the U.S."

If, as a result of these analyses, the contention can be established as false, then implemented technology is examined for potential improvements to meet the 90/90 criterion. The magnitudes of the system component errors are examined to determine where the emphasis on technology modifications should be focused. If the performance analysis provides no basis on which to reject this contention, then one has a reasonable expectation that in 9 of 10 years, with a range of agricultural and meteorological conditions similar to the test data, the LACIE production estimates would be within ±10 percent of the SRS figure at the national level.

Resonable expectation is the chosen terminology because, at this early date, it is not possible to determine directly from the available data the manner in which the LACIE production estimates would distribute about the SRS national production estimate. To determine this distribution, the LACIE experiment would have to be replicated and such replication would require excessive resources. In lieu of a knowledge of this distribution, the 90/90 criterion is evaluated in terms of the estimated variance and bias of the production estimator, under the assumption that the estimator would produce normally distributed estimates in replicated trials. Under this assumption of normality, the probability that the LACIE national estimator will produce an estimate within ±10 percent of the SRS national estimate can be related to the computed variance and bias of the LACIE estimator.

Since the production estimator is the sum over the region under study of products of area estimates and yield estimates obtained for the coincident yield and area strata (e.g., U.S. Crop Reporting Districts (CRD)), its statistical properties can be derived from a knowledge of the statistical properties of the area

and yield estimators. In Phase I, it was assumed that the errors of the yield and area estimators were uncorrelated with each other. This approximation can be modified if experience reveals that there is indeed some correlation. Under this assumption, the coefficient of variation (c.v.) of the production estimator (estimator variance divided by the expected value of the estimate) is given by $(c.v._P)^2 = (c.v._A)^2 + (c.v._Y)^2 + (c.v._A \times c.v._Y)^2$. The c.v. of the area and yield estimators ($c.v._A$ and $c.v._Y$, respectively) are computed by comparison to SRS or agricultural census data at various geographic levels using techniques to be discussed in Appendices B and C. Since the 90/90 criterion is for the national level and the LACIE estimates are for the Great Plains, the c.v. computed at the Great Plains level must be projected to the national level. The projection used will be valid if the estimator performance as determined in the Great Plains is representative of the remainder of the U.S. wheat region. It can be shown that if the variances of the production estimator in strata exterior to the Great Plains are equal to or less than the strata variances encountered in the Great Plains then $c.v._P$ for the national estimate should decrease, at the least, in proportion to the square root of production increase from the Great Plains to the national level. Given the normality assumption, it can be shown that the 90/90 criterion can be satisfied for a range of $c.v._P$ and bias. In case the estimator is unbiased, $c.v._P$ can be as large as 6 percent and satisfy the 90/90 criterion. As the magnitude of the estimator bias increases, there must be a corresponding decrease in $c.v._P$ to retain the 90/90 standard. For example, if the bias is 5 percent, then the $c.v._P$ must be 4 percent or less.

The bias of an estimator with respect to a particular data set is defined to be the average value of the differences between the estimates and the "true" value as determined from a set of replicated trials using the estimator. Thus, to compute directly the bias of the LACIE estimator, a multispectral and meteorological data set would need to be repeatedly analyzed to obtain replicated estimates of production. The average difference between the reference value and the set of estimates so obtained would provide an estimate of the bias attributable to the estimator.

Such an experiment on a large scale is obviously prohibitive; however, tests can be conducted to determine the probability that the estimator is biased as discussed below.

Since the production estimator is known to have a random error component with magnitude $c.v._P$, replication of this experiment would produce observed relative differences with a distribution of values; most of these values would lie in an interval bounded by the average relative difference $\pm c.v._P$. For example, 90 percent of them should be contained in the internal bounded by the average relative difference $\pm 1.645\ c.v._P$. Thus, if it is assumed that the LACIE production estimator is unbiased; i.e., the average relative difference is zero, 90 percent of the observed relative differences should be between $\pm 1.645\ c.v._P$. Therefore, for a particular value of the relative difference (given an unbiased estimator), there is less than a 10 percent chance that a particular relative difference would lie outside the interval $\pm 1.645\ c.v._P$.

Thus, in LACIE, the c.v. of the production estimator is computed from the data as previously described. If the relative difference

between the LACIE production estimate and the reference standard estimate is between ±1.645 $c.v._P$, the data are considered insufficient evidence to establish the existence of a bias. If the observed $c.v._P$ is 6 percent or less, then there is a reasonable expectation that the LACIE production estimator will satisfy the 90/90 criterion. As $c.v._P$ becomes smaller than 6 percent, it is known that some degree of bias can be tolerated and the confidence that the LACIE estimator will satisfy the 90/90 criterion is increased.

The performance of the LACIE estimator is also examined at geographic sublevels within the Great Plains to determine the dependence of the performance parameters on geographic factors such as cropping practice (field size, rotation systems, etc.) and climatology. Since the LACIE estimator is designed for most accurate estimation at the national level, the estimation accuracies at the state levels are considerably poorer than at the larger levels; however, examination of the relative size of the errors from one locale to another is extremely useful in detecting problem conditions, i.e., agricultural or climatic conditions which strongly affect the LACIE estimation performance.

A2 PRODUCTION ESTIMATION FEASIBILITY TESTS

In Phase I, several alternative approaches to production estimation were evaluated. Estimates from three yield estimators as well as estimates from two area estimators were combined and evaluated for production estimation. In addition, one yield estimator was utilized to produce yield estimates at both the crop reporting district and the state level to evaluate the effect on production estimation accuracy of combining yield with area at these two levels.

The two area estimators utilized differed only insofar as the inclusion or exclusion of "Group II segments" in LACIE area estimates. These are segments within Group II counties in which wheat is so sparse that one segment is used to estimate the area within several such counties. The contribution to accuracy of the Group II estimation approach was in question since area is more difficult to estimate in segments with small percentages of wheat. In one estimator the LACIE area estimates for these segments were used as originally planned in LACIE. In the other estimator the Group II segment estimates were not used and these counties treated as Group III counties where area is estimated using ratios of historic to current area estimates between these counties and Group I counties. This test permitted the Group II estimation concept to be evaluated for reduction, if any, in overall area and production estimation error.

The yield estimators, discussed in Appendix B were all variants of a basic regression approach utilizing monthly average temperature and precipitation as the prime weather variables, with a trend term to account for other effects on yield. One alternative referred to herein as the "flagged" model, utilized the basic regression model with quantitative upper and lower bounds on the values which the weather variables were not allowed to exceed. This approach, a purely heuristic one, was taken to eliminate unrealistically high or low values of yield estimates obtained with the original approach in some years when unusual amounts of precipitation was known to occur. A final variant utilized the "flagged" model, and an "improved fit" for the trend term, using the yield data, prior to the 1974-75 crop year. This test, referred to as the "trend-adjusted" test was conducted to determine the errors in production estimation being introduced by errors in the determination of the trend term.

Comparisons of the LACIE and SRS production estimates are at-harvest. These at-harvest estimates are made after wheat has been observed by Landsat through maturity and after at-harvest measurements of the weather variables have been utilized in the yield models.

A3 RESULTS

Utilizing the yield estimates obtained by basic yield regression approach and the area estimates from the planned LACIE area estimation approach, these estimates were combined at the crop reporting district level and the resulting production estimates, summed to the Great Plains level. This produced an at-harvest production estimate for the U.S. Great Plains of 1,253,300 bushels compared to 1,363,400 bushels as estimated by the SRS. The absolute difference between these two estimates is about 110,000 bushels, indicating a relative difference of -8.79 percent from the LACIE estimate. The standard deviation computed for the LACIE estimate was 66,500 bushels or 5.31 percent of the LACIE estimate. This latter percentage, the estimated coefficient of variation (c.v.) in the LACIE estimate at the Great Plains level, is projected to decrease to 4.24 percent at the national level, given the conditions discussed in the previous Section, A2.

Comparing these quantities to those required to meet the 90/90 criterion, it is noted that the c.v. of 4.24 percent projected to the national level is well within the 6 percent required for the 90/90 estimates. In addition the relative difference between the LACIE and the SRS of -8.79 percent is not sufficiently large to indicate a statistically significant underestimate. Thus, based on this feasibility test, there is a reasonable expectation that the LACIE approach will satisfy the 90/90 criterion.

Turning to Table A-I, it can be seen that the originally proposed LACIE area estimator, when combined with any of the alternate yield approaches should also satisfy the 90/90 criterion. Note in addition that the use of the LACIE area estimates in the Group II segments (see Section A2) provide improved area and production estimates in all cases when compared to the alternate area estimation approach in which Group II segment estimates were not used.

Table A-II[2] contains a more detailed comparison at levels below the Great Plains for the area estimator utilizing Group II segments and the original yield model (first column of Table A-I). As noted in Section A2 these performance numbers are computed to detect conditions which might degrade the LACIE estimator performance. In this table, it can be seen that although a considerable fraction of the segments was lost to cloud cover, the area estimates at the Great Plains level did not apparently suffer to an intolerable degree since they were acceptable for making production estimates which met the 90/90 criterion. Results for other estimators are shown in Tables A-III and A-IV.

---

[2]Since this Evaluation Report was compiled refinements have been made using the Landsat mosaics to improve the estimate of the agricultural area per stratum. These refinements improved somewhat the area (and hence production) estimates reported herein, but do not change the basic conclusion of the evaluation. At the Great Plains level, the relative difference changes by less than 1/10 of 1 percent. For one state (Montana) the difference is about 1 percent, for other states it is negligible. The c.v. is in most cases reduced (i.e., less variance in the estimate).

TABLE A-I.- PRODUCTION FEASIBILITY TEST RESULTS (U. S. GREAT PLAINS)

YIELD ESTIMATORS / AREA ESTIMATORS		ORIGINAL REGRESSION MODEL: CRD	ORIGINAL REGRESSION MODEL: STATE	FLAGGING AT STATE LEVEL	FLAG + TREND ADJUST AT STATE LEVEL
		R.D. = 2.73% C.V. = 1.66%	R.D. = 0.7% C.V. = 3.29%	R.D. = 4.25% C.V. = 2.29%	R.D. = 2.05% C.V. = 1.90%
	R.D. ± C.V.	PRODUCTION R.D. ± C.V.	PRODUCTION R.D. ± C.V.	PRODUCTION R.D. ± C.V.	PRODUCTION R.D. ± C.V.
UTILIZING GROUP II SEGMENTS	−10.71 ± 5.66	−8.79 ± 5.31	−8.75 ± 6.03	−5.62 ± 5.87	−8.52 ± 5.75
GROUP II TREATED AS GROUP III	−10.44 ± 8.84	−10.44 ± 8.94	−12.73 ± 9.13	−9.40 ± 8.91	−12.69 ± 8.79

R.D. = RELATIVE DIFFERENCE = (LACIE − SRS) ÷ LACIE

C.V. = COEFFICIENT OF VARIATION = $\sqrt{\text{VAR(LACIE)}}$ ÷ LACIE

TABLE A-II.- RELATIVE DIFFERENCE AND COEFFICIENT OF VARIATION OF LACIE ESTIMATES
(YIELD-ORIGINAL CCEA MODELS OPERATED AT CRD LEVEL)

REGION	NUMBER OF SEGMENTS UTILIZED/ ALLOCATED	PRODUCTION RELATIVE DIFFERENCE (%) ± COEFFICIENT OF VARIATION (%)	AREA RELATIVE DIFFERENCE (%) ± COEFFICIENT OF VARIATION (%)	YIELD RELATIVE DIFFERENCE (%) ± COEFFICIENT OF VARIATION (%)
WINTER WHEAT				
COLORADO	24/ 32	32.93 ± 20.71	26.10 ± 20.80	9.49 ± 5.79
KANSAS	55/ 84	20.66 ± 8.06	6.50 ± 7.07	9.69 ± 3.30
NEBRASKA	23/ 35	−20.69 ± 28.12	−15.54 ± 28.00	4.95 ± 3.36
OKLAHOMA	29/ 40	−12.55 ± 12.40	2.98 ± 11.19	−13.10 ± 4.50
TEXAS	28/ 49	−30.97 ± 28.71	−35.14 ± 32.62	.73 ± 4.27
TOTAL WINTER WHEAT	159/240	6.01 ± 6.69	− .17 ± 6.95	5.11 ± 1.92
SPRING WHEAT AND MIXED WINTER AND SPRING WHEAT				
MINNESOTA	9/ 13	−33.23 ± 12.72	−32.28 ± 15.67	.10 ± 4.42
NORTH DAKOTA	42/ 65	−88.75 ± 12.91	−74.49 ± 14.81	−26.22 ± 7.24
MONTANA	39/ 60	−33.21 ± 22.65	−24.19 ± 25.94	.13 ± 3.71
SOUTH DAKOTA	23/ 33	−27.79 ± 13.79	27.71 ± 17.65	44.44 ± 3.10
TOTAL SPRING WHEAT AND MIXED WINTER AND SPRING WHEAT	113/171	−39.14 ± 8.59	−30.14 ± 9.75	.74 ± 3.01
GREAT PLAINS	272/411	− 8.79 ± 5.31	−10.71 ± 5.66	2.73 ± 1.66
NATIONAL PROJECTION	272/637	COEFFICIENT OF VARIATION FOR PRODUCTION = 4.24	± 3.7	

ORIGINAL PAGE IS OF POOR QUALITY

TABLE A-III.- RELATIVE DIFFERENCE AND COEFFICIENT OF VARIATION OF LACIE ESTIMATES
(YIELD-ORIGINAL CCEA MODELS OPERATED AT STATE LEVEL)

REGION	NUMBER OF SEGMENTS UTILIZED/ ALLOCATED	PRODUCTION RELATIVE DIFFERENCE (%) ± COEFFICIENT OF VARIATION (%)	AREA RELATIVE DIFFERENCE (%) ± COEFFICIENT OF VARIATION (%)	YIELD RELATIVE DIFFERENCE (%) ± COEFFICIENT OF VARIATION (%)
WINTER WHEAT				
COLORADO	24/ 32	33.09 ± 21.84	26.10 ± 20.80	9.64 ± 6.82
KANSAS	55/ 84	20.48 ± 8.11	6.50 ± 7.07	14.96 ± 3.98
NEBRASKA	23/ 35	− 8.11 ± 28.40	−15.54 ± 28.00	6.43 ± 4.94
OKLAHOMA	29/ 40	−12.48 ± 14.70	2.98 ± 11.19	−15.94 ± 9.59
TEXAS	28/ 49	−60.21 ± 33.37	−35.14 ± 32.62	−18.56 ± 7.41
TOTAL WINTER WHEAT	159/240	4.93 ± 7.01	− 0.13 ± 6.95	3.80 ± 2.86
SPRING WHEAT AND MIXED WINTER AND SPRING WHEAT				
MINNESOTA	9/ 13	−35.28 ± 17.21	−32.28 ± 15.67	− 2.[illegible]2 ± 7.20
NORTH DAKOTA	42/ 65	−85.13 ± 20.85	−74.49 ± 14.81	− 6.15 ± 14.83
MONTANA	39/ 60	−32.39 ± 26.42	−24.19 ± 25.94	− 6.46 ± 5.21
SOUTH DAKOTA	23/ 33	33.46 ± 18.88	27.71 ± 17.65	7.86 ± 6.83
TOTAL SPRING WHEAT AND MIXED WINTER AND SPRING WHEAT	113/171	−35.85 ± 11.41	−30.14 ± 9.75	− 3.70 ± 6.99
GREAT PLAINS	272/411	− 8.75 ± 6.03	−10.71 ± 5.66	.70 ± 3.29
NATIONAL PROJECTION	272/637	COEFFICIENT OF VARIATION FOR PRODUCTION = 4.82		

TABLE A-IV.- RELATIVE DIFFERENCE AND COEFFICIENT OF VARIATION OF LACIE ESTIMATES
(YIELD-FLAGGED CCEA MODELS OPERATED AT STATE LEVEL)

REGION	NUMBER OF SEGMENTS UTILIZED/ ALLOCATED	PRODUCTION RELATIVE DIFFERENCE (%) ± COEFFICIENT OF VARIATION (%)	AREA RELATIVE DIFFERENCE (%) ± COEFFICIENT OF VARIATION (%)	YIELD RELATIVE DIFFERENCE (%)
WINTER WHEAT				
COLORADO	24/ 32	33.09 ± 21.84	26.10 ± 20.80	9.64 ± 6.83
KANSAS	55/ 84	20.48 ± 8.11	6.50 ± 7.07	14.96 ± 3.98
NEBRASKA	23/ 35	− 8.43 ± 28.41	−15.54 ± 28.00	6.16 ± 4.99
OKLAHOMA	29/ 40	−18.80 ± 13.72	2.98 ± 11.19	−22.45 ± 7.99
TEXAS	28/ 49	−45.92 ± 32.90	−35.14 ± 32.62	− 7.98 ± 4.53
TOTAL WINTER WHEAT	159/240	4.95 ± 7.04	− 0.13 ± 6.95	4.15 ± 2.58
SPRING WHEAT AND MIXED WINTER AND SPRING WHEAT				
MINNESOTA	9/ 13	−35.28 ± 17.21	−32.28 ± 15.67	− 2.32 ± 7.20
NORTH DAKOTA	42/ 65	−63.08 ± 16.90	−74.49 ± 14.81	6.50 ± 8.23
MONTANA	39/ 60	−26.37 ± 26.09	−24.19 ± 25.94	− 1.62 ± 2.98
SOUTH DAKOTA	23/ 33	40.94 ± 18.55	27.71 ± 17.65	18.22 ± 5.80
TOTAL SPRING WHEAT AND MIXED WINTER AND SPRING WHEAT	113/171	−24.88 ± 10.50	−30.14 ± 9.75	4.67 ± 4.15
GREAT PLAINS	272/411	− 5.62 ± 5.87	−10.71 ± 5.66	4.25 ± 2.29
NATIONAL PROJECTION	272/637	COEFFICIENT OF VARIATION FOR PRODUCTION = 4.69		

It can be generally stated that the relative difference in the SRS and LACIE state level estimates fluctuate evenly on both sides of zero, indicating that the LACIE estimators are not significantly biased. At the Great Plains level, statistical tests indicate no significant bias in the yield or production estimates. However, the LACIE area estimator is significantly underestimating at this level. A check at the subregion level indicates the source of the problem to be the northern Great Plains. The winter wheat area in the southern Great Plains has been estimated quite closely. Examining each of the northern Plains states the source of error appears to be located in North Dakota, where the area difference between LACIE and SRS is significant. Further examination of this problem, undertaken to determine if the area estimation problem is sampling error or classification error indicated (see Appendix C, Section C4, and Table C-IV) the major source appears to be sampling error. Efforts are underway to correct this for Phases II and III.

From the subregional yield performances it can be seen that the yield model is relatively less accurate in North Dakota than elsewhere and also seems to perform better on winter wheat although the model is significantly overestimating yield in Kansas. These errors are discussed in Appendix B.

In summary, the production feasibility tests are quite encouraging in that they indicate the 90/90 criterion can be met. Generally it would appear that the estimation accuracies are better for winter wheat than for spring wheat. There is some concern over the performance in North Dakota and this problem is being investigated for solutions in Phases II and III.

APPENDIX B

SUMMARY OF YIELD ACCURACY ASSESSMENT

B1 ACCURACY ASSESSMENT METHODOLOGY

As discussed in Appendices A and C, error budgets have been developed for accuracy assessment which permit an evaluation of the utility of a yield estimator as a component in a 90/90 production estimator. This analysis requires that the area estimator be unbiased, that its errors be uncorrelated to the errors in yield estimation, and that it have a coefficient of variation (c.v.) of 4.25 percent or less. If the yield estimator can be shown to satisfy the same criterion as the area criterion, then it is judged a suitable estimator.

Because the yield estimator is a regression-type estimator, developed from an existing historic data base of reported yields and recorded weather, it was possible to conduct some evaluations using this historic base. These were in addition to tests described in Appendix A in which the Phase I yield estimates were combined directly with Phase I area results and evaluated.

Based on the historic yield and meteorological data for the 11 years from 1965 to 1975 for the U.S. Great Plains, eleven separate trials were run in which the regression models were developed on years of record prior to each of these years and then exercised on the test year. For each of the 11 test years, performance was evaluated in two different ways.

In the first approach, the coefficient of variation of the yield estimate was computed as the standard error of the regression

estimate divided by the LACIE value for the yield. In addition, the observed relative difference between the SRS reported value and the LACIE estimated value was also computed. These performance data are computed for estimates at both the state and CRD levels.

The coefficients of variation computed for the Great Plains are then projected[1] to the U.S. national level and compared to the 4.25 percent criterion. If this criterion is satisfied and the bias test does not detect a bias, then the model is judged satisfactory.

An alternate method using the historic data base for evaluating the ability of the LACIE yield estimator to satisfy the 90/90 criterion has been developed based on comparisons of the products of the LACIE yield estimates and the SRS area estimates to the SRS production estimates for each of the test years. Since for a given year the products of SRS reported area and the reported yields equal the SRS reported production, the differences between the SRS production figures and the test production estimates so obtained can be attributed solely to differences in the SRS and LACIE yields. These differences will, of course, be weighted by the reported area in the various strata.

A criterion has also been developed to ascertain the statistical properties which these test production estimates must have in relation to the 90/90 criterion. To develop the test

---

[1]This projection assumes $c.v._Y$ to decrease in proportion to the square root of the increase in production from the Great Plains to the national level.

estimate criterion, equal amounts of random error are attributed to the yield and area estimators. Under this assumption it can be shown that if, in eight out of ten test cases, production estimates at the Great Plains level are within a tolerance bound of ±9.5 percent of the SRS production estimates, the LACIE yield estimates can be reasonably expected to satisfy the 90/90 criterion at the national level. In addition, tolerance bounds at the state levels can also be computed by assuming an increase in the Great Plains tolerance bounds proportional to the square root of the decrease in total production to the state levels. Thus, if eight of ten of the state test production estimates fall within these state level tolerance bounds, the state estimator is judged adequate. In such a case, the yield estimator could be expected to produce 90/90 estimates for a region producing about the same amount of wheat as the U.S. and in which agricultural and climatic conditions were similar to those of the particular test state.

B2 YIELD ESTIMATION FEASIBILITY TESTS

One basic yield estimation approach was tested in Phase I over the Great Plains, with two variants of this basic approach also evaluated for assessment of potential improvements. The basic regression approach utilized monthly average temperature and precipitation as the weather variables with a trend term to account for other effects.

One alternative, referred to herein as the "flagged" model, utilized the basic regression model with quantitative upper and lower bounds on the values which the input variables were not allowed to exceed. If the monthly average precipitation exceeded the 90th percentile value, or if the monthly average

temperature exceeded the 5th or 95th percentile value, as determined from historic data, the value of the input variable for the model was set to that particular percentile value. This approach, purely heuristic, was taken to eliminate unrealistically high or low values of yield estimates obtained in certain instances in the evaluation of the original model. Of course, flagging daily, instead of monthly, values of these parameters should be more effective in eliminating effects due to anomalous meteorological phenomena, but for Phase I such data was not used in the LACIE models.

A final variation utilized the "flagged" model and an "improved fit" for the trend term. This fit was chosen using the yield data prior to the 1975 crop year.

The original regression model was also exercised at both the crop reporting district and at the state level, the alternates at only the state level. In the U.S. Great Plains there are models for each of twelve regions, each model developed by conducting a regression of historic yield values for the region against the historic meteorological data for the region. Once the coefficients have been determined, the weather at any level can be input to the model to obtain a yield estimate. Thus, in anticipation that a combination of the LACIE yield and area estimates at a geographic level below the state might be more optimum for production estimation, a test was conducted using the crop reporting district yield estimates obtained by exercising the models with weather for the crop reporting district. It should be noted this is at best an approximation to the performance obtainable by developing regression models for each crop reporting district, an approach anticipated to be more accurate.

B3 RESULTS

In summary, the variety of tests on the initial yield models indicated they are marginally suitable as LACIE estimators. In reviewing the results in more detail, it was discovered that one prime contributor to the errors was the mathematical form of the regression models, which created unrealistically high or low yields when the monthly averages of the input meteorological variables tended toward extremely high or low values.

A modest change to these models was attempted by "flagging" the values, i.e., defining ranges which the input values are not allowed to exceed as described in Section B2. This change provided enough improvement so that the performance of these models is now judged satisfactory for a 90/90 production estimation as opposed to marginal as originally implemented.

The detailed results obtained by comparing the original model against the 4.25 percent criterion at the national level, as discussed in B1, is shown in Table B-I. Here we note that the CRD model has, on the average, a smaller c.v. than does the state model. The c.v. of the CRD model satisfies the 4.25 percent criterion in all years whereas the state model fails in 2 of the 11 years. However, the large relative differences (10 percent) observed in 3 of the 11 years with these models are of concern. Based on this data, the CRD model was judged marginally suitable. Table B-II shows the same results when the "flagged" model was exercised. The results of the analysis of LACIE yield estimates for the 11-year period using the test method discussed in B1 are summarized by the graphs in figures B-1 and B-2 for the original and flagged models, respectively.

TABLE B-I.- ESTIMATED COEFFICIENT OF VARIATION AND RELATIVE DIFFERENCE OF YIELD ESTIMATES AT THE NATIONAL LEVEL (ORIGINAL YIELD MODEL)

Year	Yield estimated at the Crop Reporting District level		Yield estimated at the State level	
	Relative difference, percent (a)	c.v., percent (b)	Relative difference, percent (a)	c.v., percent (b)
1975	0.9	0.4	6.0	1.6
1974	18.5+	1.0	14.7+	2.3
1973	18.6+	3.0	13.9+	5.5
1972	-1.7+	.8	-2.1	2.0
1971	-9.4+	.8	-9.5+	2.4
1970	-6.8+	1.0	-7.7+	2.7
1969	4.9+	1.0	5.4+	2.0
1968	1.5	1.0	-5.5+	2.4
1967	-7.7+	1.6	-7.8	4.5
1966	11.9+	1.4	10.3+	2.8
1965	-0.8	1.3	-1.9	3.0

[a]Actual calculated at Great Plains level. Significance test utilized computed c.v. for Great Plains.

[b]Projected from Great Plains to national level under the assumption that c.v. will decrease in proportion to increase in production.

NOTE: The relative difference is normalized with respect to SRS production estimates because these were readily available for the 10-year retrospective test period.

TABLE B-II.- ESTIMATED COEFFICIENT OF VARIATION AND RELATIVE DIFFERENCE OF YIELD ESTIMATES AT THE NATIONAL LEVEL (FLAGGED YIELD MODELS)

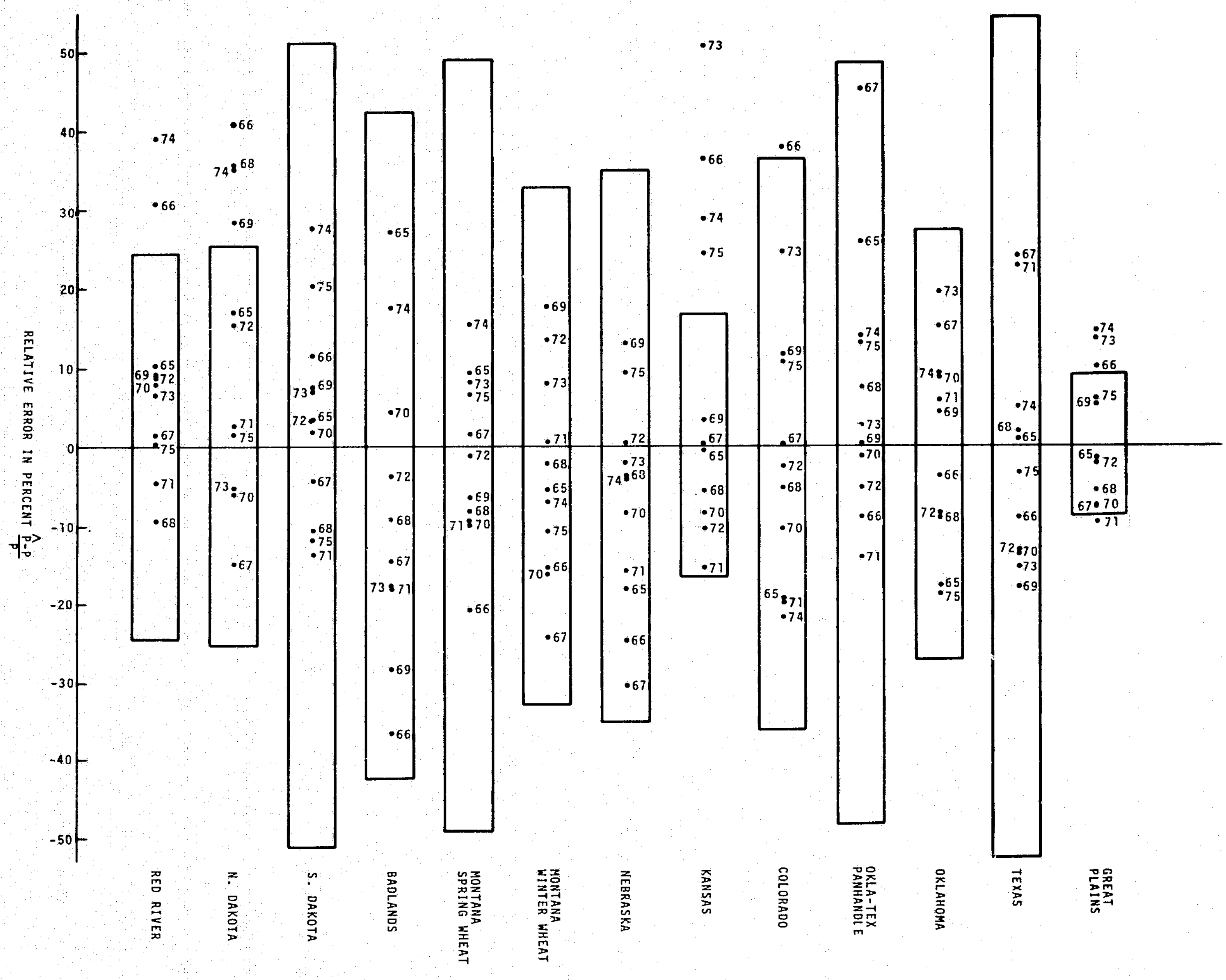
Year	Yield Estimated at the State level	
	Relative difference, percent (a)	c.v., percent (b)
1975	5.1+	1.7
1974	17.9+	1.9
1973	-1.5	1.7
1972	-0.7	1.6
1971	-8.6+	1.9
1970	-4.6+	2.1
1969	3.6	1.7
1968	-4.7+	1.9
1967	3.3	2.6
1966	8.7+	2.7
1965	1.6	2.3

[a]Actual calculated at Great Plains level. Significance test utilized computed c.v. for Great Plains.

[b]Projected from Great Plains to national level under the assumption that c.v. will decrease in proportion to increase in production.

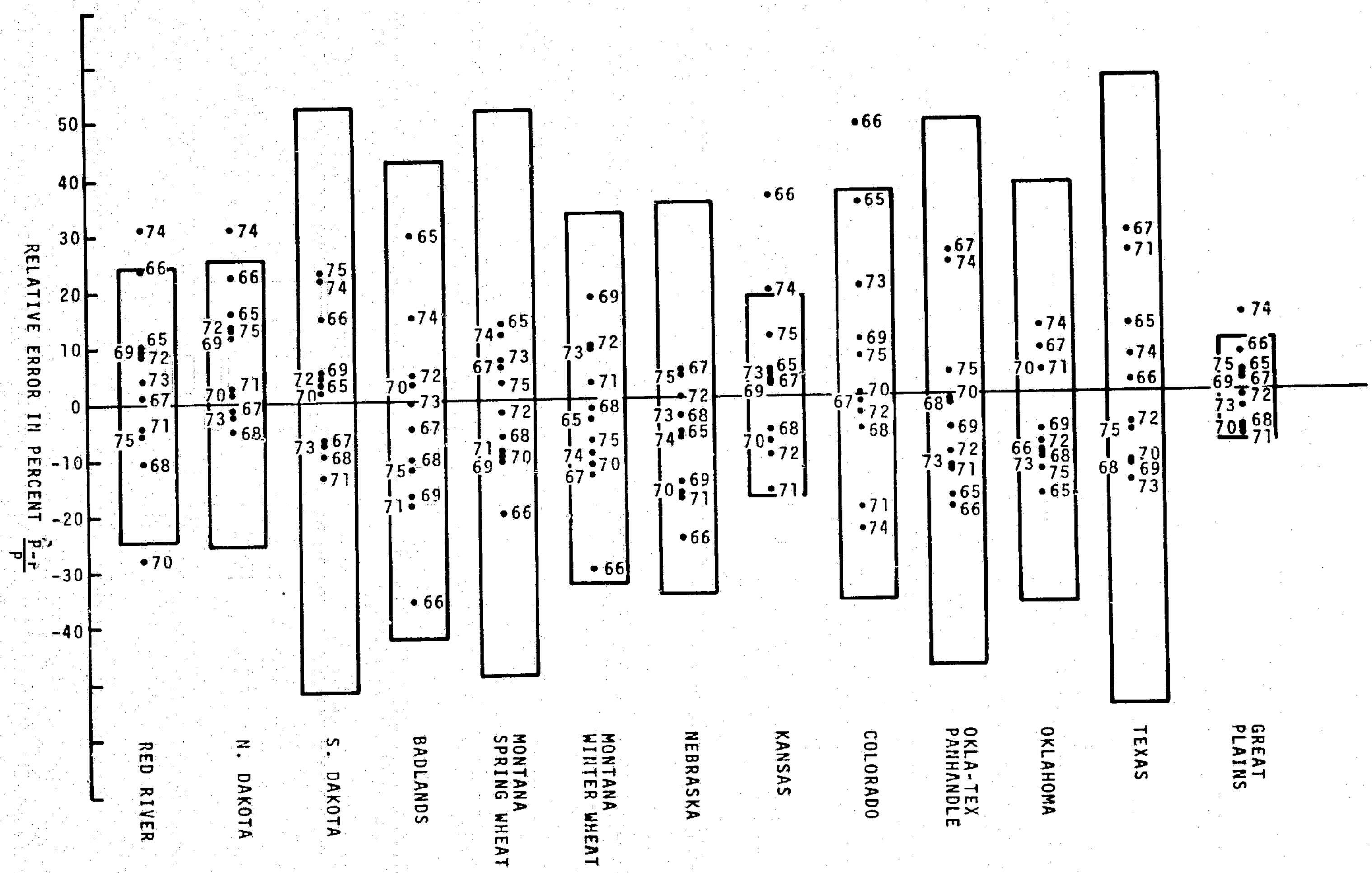
NOTE: The relative difference is normalized with respect to SRS production estimates because these were readily available for the 10-year retrospective test period.

ORIGINAL PAGE IS OF POOR QUALITY



BARS ARE TOLERANCE BOUNDS PROJECTED TO NATIONAL LEVEL (USING 1974 SRS PRODUCTION PROPORTIONS)
TOLERANCE BOUNDS ASSUME AREA COEFFICIENT OF VARIATION TO BE EQUAL TO YIELD COEFFICIENT OF VARIATION
$\hat{P}$=TEST PRODUCTION BASED ON LACIE YIELD ESTIMATES AT "STATE" LEVEL
P=SRS PRODUCTION

Figure B-1.- Eleven-year (1965-1975) yield model evaluation (original models).



BARS ARE TOLERANCE BOUNDS PROJECTED TO NATIONAL LEVEL (USING 1974 SRS PRODUCTION ESTIMATES)

TOLERANCE BOUNDS ASSUME ACREAGE COEFFICIENT OF VARIATION TO EQUAL TO YIELD COEFFICIENT OF VARIATION

$\hat{P}$ = PROJECTED PRODUCTION BASED ON LACIE YIELD ESTIMATES

P = SRS PRODUCTION

Figure B-2.- Eleven-year (1965-1975) upgraded yield model evaluation.

Recall that in this method the analysis of yield estimates is in terms of the capability to contribute to acceptable production estimates, given accurate area estimates. Production in this case is computed by multiplying SRS state area estimates by LACIE state yield estimates. The relative differences[2] of the resulting production estimates are indicated by the dots on the graph, and the numbers next to those dots refer to the calendar year for which each estimate was made. The bars on the graph are tolerance bounds on these relative differences projected to national level. Eight out of ten of the relative differences falling within the tolerance bounds indicates the acceptance of the hypothesis that the 90/90 production criterion at the national level is met. The test of similar hypothesis is done for the individual states[3] to determine which types of geographic areas that may represent problem areas.

It is seen in figure B-1 that the hypothesis would be rejected for the Great Plains; in other words, the yield estimates considered collectively over the nine Great Plains states do not support the 90/90 criterion. The figure indicates that a partial explanation for this conclusion can be traced to the generally poor estimates in 1973 and 1974 and to the poor performance of the North Dakota and Kansas state yield models. These also are the only two geographic "areas" for which the hypothesis would be rejected at a national level if the entire country behaved like either of these areas. In the case of

---

[2]Relative difference (percent) = $\dfrac{\text{LACIE production} - \text{SRS production}}{\text{LACIE production}} \times 100.$

[3]Note: The 90/90 criterion is applicable only to a country level.

North Dakota and Kansas, the results shown in figure B-1 tend to support this conclusion. In that figure, a bias is indicated in the Kansas yield estimate and a large variance is shown to be associated with the North Dakota yield estimate.

B3 PROJECTION TO FOREIGN AREAS

It should be kept in mind that these accuracy figures apply to the U.S. Great Plains yield models. Accuracies may degrade to some extent in those foreign areas where historical yield and weather data bases are less adequate for modeling and real-time weather inputs to models rely on very sparse reporting networks.

APPENDIX C

<u>SUMMARY OF AREA ACCURACY ASSESSMENT</u>

C1 ACCURACY ASSESSMENT METHODOLOGY

In Appendix A, the methodology for the assessment of the LACIE wheat production estimator accuracy was described. Given certain assumptions regarding the manner in which the production estimates would distribute about the reference production estimate (the assumption of normalcy was invoked), methods were outlined for relating the variance and bias of the production estimator to the 90/90 criterion. It was concluded that, in case statistical tests do not detect bias in the estimator and the computed coefficient of variation is 6 percent or less, there is a reasonable expectation that the production estimator satisfies the 90/90 criterion. The term <u>reasonable expectation</u> is expounded on in some detail in that appendix.

Since the LACIE production estimator is the sum of products of the area and yield estimates obtained for the coincident yield and area strata (e.g., U.S. crop reporting districts) covering the survey region, its statistical properties can be derived from a knowledge of the statistical properties of the yield and area estimators.

An approximate[1] relation has been derived which expresses the c.v. of the production estimate ($c.v._P$) in terms of the c.v.

---

[1]A more exact expression involves sums of coefficients of variation obtained at the stratum level.

of the area estimate ($c.v._A$) and the c.v. of the yield estimate ($c.v._Y$). This expression is

$$(c.v._P)^2 = (c.v._A)^2 + (c.v._Y)^2 + (c.v._A \times c.v._Y)^2 \qquad (C\text{-}1)$$

In LACIE, this relationship permits the development of an error budget which permits separate criteria to be established for the area and yield estimators. In Phase I it was assumed that the yield estimator would be as accurate as the area estimator and vice versa. Thus, $c.v._A$ was assumed equal to $c.v._Y$. Under this hypothesis, equation C-1 can be solved for $c.v._A = c.v._Y$ to ascertain what value of these parameters would be required to obtain the $c.v._P$ of 6 percent needed for 90/90 estimates. The values so obtained are $c.v._A = c.v._Y \leq 4.25$ percent.

Thus, if the area estimator is shown to have a c.v. of $\leq$ 4.25 percent and is unbiased, it is considered, with reasonable expectation, to be a satisfactory component in the overall production estimator — similarly for yield.

However, it should be remembered that the final test is the combination of area and yield as was discussed in Appendix A. The error budget simply provides a method for ascertaining the general quality of the area and yield estimators independent of each other in relation to the 90/90 criterion for production. In fact, if the area estimator has a c.v. of greater than 4.25 percent and the yield estimator less than 4.25 percent, the production estimator could still be satisfactory.

In addition, the 4.25 percent random error assignment to area permits a more detailed evaluation of the random components of

the sampling and classification error contributions to the area estimator. The random component of the sample error is a measure of the degree to which, in replicated sample draws, the wheat area contained in the LACIE samples represents the wheat area contained in the survey region being sampled. The random component of the classification error is a measure of the degree of repeatability with which the LACIE Classification and Mensuration Subsystem (CAMS) could estimate, in replicated trials, the area contained in one or more LACIE samples. The total area estimator random error component is, of course, a measure of the degree of repeatability with which the LACIE area estimator could be expected, in replicated trials, to estimate the actual area contained in the survey region.

The assumption has been made that the classification and sample errors are independent; i.e., the classification error is not systematically affected by the sample location. Under these conditions, the coefficient of variation of the total area estimate can be expressed in terms of the random components of the classification error $c.v._C$ and sample error $c.v._S$ as

$$(c.v._A)^2 = (c.v._C)^2 + (c.v._S)^2 \qquad \text{(C-2)}$$

$c.v._S$ has been estimated in LACIE to be about 2 percent at the national level. Since $c.v._A$ at this level should be about 4.25 percent, this would, according to equation, C-2 permit a random component to the classification error of 3.74 percent.

What is meant by this latter statement is, if the N_t LACIE samples allocated nationally were repeatedly classified in independent repeated trials, the coefficient of variation of

the set of estimates of the areas contained within the N_t sample segments[2] should be 3.74 percent or less if the classification technology is to be judged suitable as a component in the overall production estimator.

This latter criterion is a very important one since it provides a method for assessing the viability of the classification technology against a quantitative criterion. This criterion can also be used to determine the allowable magnitude of the random component of classification error for any number (n) of segments by the relation

$$\text{c.v.}_A^n = \sqrt{\frac{N_t}{n}}\ \text{c.v.}_A^{N_t} \qquad \text{(C-3)}$$

Thus, assuming that 431[3] of the 637 segments will be acquired cloud free, the allowable random error for a collection of n such segments would be

$$\text{c.v.}_A^n = \sqrt{\frac{431}{n}} \times 3.74\% \qquad \text{(C-4)}$$

Thus, for a single sample segment the tolerable random error component is given for n = 1 or approximately 80 percent.

Thus, if the <u>classifier is unbiased</u> and 431 of the 637 sample segments are acquired suitably for classification, the area

---

[2] 637 in the U.S.

[3] Based on statistics from Phase I.

estimate for a 5 × 6 n. mi. segment must be, in a majority[4] of instances, to within about 80 percent of the true wheat area contained by the segment.

A similar analysis for sampling error, based on the 2 percent goal at the national level indicates that on a per segment basis the tolerable random component is about 40 percent. This can be interpreted to mean that the actual wheat prevalence in the sample segment should be to within about 40 percent of the actual prevalence in the stratum in a majority[5] of instances.

Tests have shown these random error magnitudes are obtainable given the currently implemented LACIE technology, Thus, segments must be allocated and analyzed in a manner which minimizes bias. Bias in classification results from mistaken identification of wheat as nonwheat and vice versa. If on the average these mistakes tend to cancel, the segment area estimator will be unbiased. Thus, the aim of classification technology is to produce the smallest possible error rate in a manner for which classification of wheat as nonwheat tends, on the average, to cancel the mistaken identifications of nonwheat as wheat.

Sample error in the form of bias can also creep into the design, even though the sample selection is random. Such bias can result purely from a "luck of the draw" phenomenon; that

---

[4]In 67 percent of the measurements given a normal distribution.

[5]In 67 percent of the estimates given a normal distribution.

is, any particular configuration obtained in a sample draw has a probability to contain either more or less wheat then is in the sampled region. Since the LACIE sample remains fixed[6] from year to year, a particular sample configuration will contain a fixed bias.

C2 AREA ESTIMATION QUASI-OPERATIONAL TESTS

In Phase I, three sets of area estimates were produced for the U.S. Great Plains. The initial quasi-operational system produced area estimates real-time. This operation was primarily concerned with "debugging" the system. Several serious implementation problems were uncovered in this real-time operation. In lieu of a real-time cropping calendar, the Landsat data was acquired at dates determined from historic calendars. Using this approach most of the Landsat data acquired early in the growing season in Phase I was acquired before the wheat had emerged and became visible on the Landsat imagery. Because of the importance of early estimates, area estimates were attempted using this data by declaring areas of seed bed preparation as "potential wheat." Since seed bed preparations are made for other crops, the LACIE estimates were considerably larger than the actual wheat area.

These system problems were corrected and the Landsat data reanalyzed by the LACIE CAMS. The resulting area estimates based on this reanalysis are referred to herein as the CAMS rework estimates.

---

[6]A minority of the sample segments will change from year to year resulting from variable loss to cloud cover.

Two estimates were made using the CAMS rework data. These two estimates differ only in regard to the inclusion of Group II segments. These segments, a minority in the total segment complement, are those segments within Group II counties which are so sparsely planted to wheat that one segment is used to estimate the area within several such counties. The Group II segments often contain less than 5 percent by area of wheat. Initially CAMS attempted to train the classifier and classify the segment utilizing the maximum likelihood classifier. It was found that as a result of inadequate training data and an abundance of confusion crops in such segments, this procedure tended to overestimate the amount of wheat contained. A modified procedure was developed in CAMS to estimate the wheat area in these segments. Preliminary indications were that the overestimates in these segments have been corrected. However, final judgement was reserved following comparisons of wheat area estimates and variance estimates obtained by aggregating with and without these segments.

C3 RESULTS OF THE ASSESSMENT

After correction of the significant problems in the initial implementation of the LACIE area estimation technology, the resulting area estimates satisfied the 90/90 criterion for production, in terms of criterion of being an unbiased estimator with a c.v. of less than 4.25 percent and, in particular, when combined with the actual LACIE yield estimates (see Appendix A).

The accuracies obtained using the rework estimates, including Group II segments, are shown in Table C-I.[7] Note that the coefficient of variation for this estimate projected to the national level is 3.74 percent, somewhat smaller than the 4.25 percent deemed desirable in the discussion of the previous section, and thus some bias is tolerable. However, the relative difference of -10.7 percent at the Great Plains level is sufficiently large to indicate a bias given a c.v.$_A$ of 5.66 percent at that level. Recall also that when these area estimates were combined with the yield estimates, the resulting production estimate could, with a reasonable expectation, satisfy the 90/90 criterion.

From these results in table C-I, the area of most concern as regards problem isolation and correction is North Dakota. More detailed ground truth and ancillary error analyses in Kansas, North Dakota, Nebraska, and South Dakota permitted a more detailed assessment of the sampling and classification errors. These analyses, to be discussed in Section C4, indicated the source of the North Dakota problem to be sample error.

---

[7] Since this Evaluation Report was compiled, refinements have been made using the Landsat mosaics to improve the estimate of the agricultural area per stratum. These refinements improved somewhat the area (and hence production) estimates reported herein, but do not change the basic conclusion of the evaluation. At the Great Plains level, the relative difference changes by less than 1/10 of 1 percent. For one state (Montana) the difference is about 1 percent, for other states is negligible. The c.v. is in most cases reduced (i.e., less variance in the estimate).

TABLE C-I.- ACCURACY OF AT-HARVEST ESTIMATES OF WHEAT AREA

USING CAMS REWORK DATA (GROUP II SEGMENTS INCLUDED)

Region	Number segments utilized/allocated	Computed relative difference, percent	Coefficient of variation, percent
Winter wheat			
Colorado	24/32	26.1	20.8
Kansas	55/84	6.5	7.07
Nebraska	23/35	-15.5	28.0
Oklahoma	29/40	3.0	11.2
Texas	28/49	-35.1	32.6
Total winter wheat states	159/240	-0.17	6.95
Spring/winter			
Minnesota	9/13	-32.3	15.7
N. Dakota	42/65	-74.5[a]	14.8
Montana	39/60	-24.2	25.9
S. Dakota	23/33	27.7	17.7
Total spring/winter mixed states	113/171	-30.1	9.75
Great Plains	272/411	-10.7	5.66
Projected to national	272/637		3.74

[a]Significant relative difference indicates potential bias.

ORIGINAL PAGE IS OF POOR QUALITY

Table C-II indicates the results when Group II segments were not included in the area estimator, and the associated Group II counties were treated as Group III counties. As can be seen by comparing Table C-I to Table C-II, the area estimates are significantly better when the CAMS area estimates in Group II segments are used in the aggregation.

C4 ESTIMATION OF AREA ERROR USING BLIND SITE DATA

The expression "blind site" is merely a designation applied to selected operational segments for which, unknown to the analyst, ground truth data was acquired for subsequent evaluation purposes. The implementation of this approach occurred late in the growing season of LACIE Phase I. Thus, all of the selected sites fell in the northern spring wheat regions.

High resolution color infrared aerial photography over twenty-nine LACIE segments in North Dakota and Montana (the results from only 16 of these segments in North Dakota are relevant to the basic discussion which follows) was acquired in mid-August 1975. Simultaneously, field teams were collecting ground information for a substantial portion of these segments.

These data were combined to obtain both field and total segment ground truth data. The small grain proportion estimates were statistically compared to the LACIE estimates for the 16 segments in North Dakota. This resulted in a direct computation of the classification error, $c.v._C$, for the state of North Dakota as shown in Table C-III.

TABLE C-II.- ACCURACY OF AT-HARVEST ESTIMATES OF WHEAT AREA

USING CAMS REWORK DATA (GROUP II SEGMENTS NOT INCLUDED)

Region	Number segments utilized/allocated	Computed relative difference, percent	Coefficient of variation, percent
Winter wheat			
Colorado	24/32	29.7	21.2
Kansas	55/84	3.83	9.59
Nebraska	23/35	14.9	38.6
Oklahoma	29/40	-17.5	29.5
Texas	28/49	-65.0	43.4
Total winter wheat states	159/240	-4.45	10.5
Spring/winter			
Minnesota	9/13	-136.8	122.9
N. Dakota	42/65	-74.5+	14.8
Montana	39/60	-22.8	38.7
S. Dakota	23/33	26.7	19.6
Total spring/winter mixed states	113/171	-38.4[a]	16.2
Great Plains	272/411	-16.2	8.84
Projected to national	272/637		5.8

[a]Indication of potential bias when operating in regions with agricultural and climatic conditions similar to this state.

TABLE C-III.- LACIE BLIND SITE DATA

(North Dakota spring small grains)

County	Fraction of area in small grains, percent		
	Ground truth (5x6 n. mi. segment)	LACIE (5x6 n. mi. segment)	SRS county (whole county)
Ward 1	13.2	17.1	33.8
Ward 2	26.8	8.2	33.8
Williams	3.7	0	27.5
McHenry 1	0	0	25.9
McHenry 2	0.3	0	25.9
Rolette	4.9	--	18.8
Ramsey	38.4	49.5	41.5
McKenzie 1	1.3	--	10.6
McKenzie 2	1.0	0.3	10.6
Mclean	29.3	28.4	31.7
Mercer	16.3	18.0	19.9
Oliver	15.6	--	16.2
Kidder	16.4	--	19.4
Sheridan	12.9	0	30.9
Adams	26.1	24.4	22.8
Hettinger	21.7	24.1	35.7
Burleigh	18.2	12.0	20.7
Morton	4.6	6.7	15.7
Richland	31.6	15.6	36.2
Sargent	35.0	32.3	34.7
	17.46 LACIE 16	14.78	--
Average	15.87 ALL 20	--	26.00

Correlation high between LACIE and ground truth r = 0.849.
Variance of LACIE estimates is within allowable range, c.v. = 50 percent.
No apparent bias in LACIE estimate.

This table indicates a relative difference between the classified wheat proportion and the ground observed proportion of -15 percent of the ground observed proportion - this is not indicative of a significant bias in view of the standard error. However, the difference between the ground truth estimate and the SRS county figures would explain the underestimate obtained in North Dakota. Thus, for North Dakota it was concluded that sampling error was the major source of the observed bias. Other investigations with full frame imagery confirmed this, in that agriculture is very heterogeneous in this region and many of the LACIE segments do not adequately represent the county.

C5 ESTIMATING THE SAMPLING ERROR AT THE SEGMENT LEVEL

In four states (Kansas, Nebraska, North Dakota, and South Dakota) the sampling error was estimated for selected counties (chosen primarily because of sufficient Landsat acquisitions). These estimates were for small grains. The estimates were made by a scheme using the full frame Landsat color infrared imagery in the following manner.

- The Landsat full frame was partitioned into 5 × 6 n. mi. segments.
- A subsample of these segments was used which was within county boundaries for selected counties.
- A grid containing 200 points was overlaid on the selected segments.
- An analyst then determined from imagery at each grid point whether either wheat/small grain or nonwheat/nonsmall grain was present.

The area proportion for each segment was then computed by taking the ratio of grid points identified as wheat/small grain to the total number of grid points. Then, for each county, the sampling variance (taken to be the estimate of the within-county variance) and c.v. of the wheat area estimate at the segment level within that county was computed. These c.v.'s and the wheat/small grain estimates from each of the four states were then used to obtain an average segment percent wheat and c.v.; i.e., an estimate of the segment sampling error, $\overline{c.v.}_S$. The results are depicted in Table C-IV.

TABLE C-IV.- ESTIMATE OF SAMPLING ERROR $\overline{c.v.}_S$

AT THE SEGMENT LEVEL

State	Average wheat percent	Segment level Estimate of c.v. percent
Kansas	14	47
North Dakota	22	46
Nebraska	13	28
South Dakota	20	39

The numbers shown in Table C-IV represent the first attempt within the project to compute sampling error. Some key issues can be noted. For example, when comparisons between analyst-derived wheat proportion estimates and SRS county results are made in Kansas, a consistent underestimate was apparent. However, since the errors of SRS estimates projected to the county level are unknown, no conclusions can be drawn immediately relative to possible bias.

Consideration of the foregoing and observations made of the magnitudes of the estimated $\overline{c.v._S}$ displayed in Table C-IV leads to the conclusion that the random component of sampling error, $\overline{c.v._S}$, appears to be on the order of the 40 percent figure permissible for a 2 percent national sample error.

C6 ESTIMATING THE CLASSIFICATION ERROR AT THE SEGMENT LEVEL

The data obtained (Table C-IV) at the county level were used in a standard statistical analysis to compute a sampling c.v. at the state level for each of the four states. In addition, an estimate of the total c.v. (including the effects of classification and sampling error) at the state level, $c.v._A$, was computed using the LACIE segment estimates and the SRS 1969 census data at the county level. If it is assumed, as discussed in A1.0, that $(c.v._A)^2 = (c.v._C)^2 + (c.v._S)^2$, then it follows immediately that an estimate of $c.v._C$ at the state level can be obtained.

By considering the number of samples in the state, an estimate of classification error at the segment level $\overline{c.v._C}$ is obtained for each state and is depicted in Table C-V.

TABLE C-V.- ESTIMATE OF CLASSIFICATION ERROR

$\overline{c.v.}_C$ AT THE SEGMENT LEVEL

State	State level			Segment level
	Estimated $c.v._A$, percent	Estimated $c.v._S$, percent	Estimated $c.v._C$, percent	Estimated $\overline{c.v.}_C$
Kansas	10	6	8	59
N. Dakota	15	13	10	65
Nebraska	39	12	37	161
S. Dakota	20	14	16	73

Observation of Table C-V indicates the following:

- In all states but Nebraska, the classification error at the state level is acceptable and is about equal to the sampling error at the state level, i.e., $c.v._S = c.v._C$.
- Classification error at the state level in Nebraska, known to result from confusion crops, indicates a potential problem.

In addition, one can conclude from Tables C-IV and C-V that in North Dakota the observed relative difference does not appear to result from the random components of classification error, $c.v._C$, and sampling error, $c.v._S$. Thus, a systematic problem may exist within the allocation of the LACIE North Dakota segments.

In Table C-VI are presented the results of an independent estimate of the classification and sampling error using the blind site data. The $c.v._C$ is computed from the differences in the LACIE and ground truth proportion estimates

(Table C-III). The $c.v._S$ is computed from comparisons of the ground truth and SRS county figures in Table C-III.

It should be noted that the sampling and classification errors determined by this method for North Dakota compare very favorably with errors shown in Table C-V, thus establishing some agreement among the various approximate methods utilized to compute sample and classification errors.

TABLE C-VI.- BLIND SITE ESTIMATES OF SAMPLING AND CLASSIFICATION ERROR AT THE STATE LEVEL

State	Estimates $c.v._S$, percent	Estimated $c.v._C$, percent
North Dakota	10	10

C7 SUMMARY

It appears that the LACIE area estimates over the Great Plains, can with a reasonable expectation, be a satisfactory component of a 90/90 production estimator. The area estimator produced more accurate area estimates for the total winter wheat region than for the mixed spring and winter wheat region of the northern Great Plains. The major problem in the spring/winter states appears to be North Dakota. Detailed tests indicate that sample error is the source of the problem. Phase I comparisons of LACIE estimates with ground truth indicates that the LACIE classification technology is working acceptably well. The accuracy does appear to degrade somewhat in regions of

marginal agriculture where there are small fields and abundant confusion crops. However, it would appear that these regions tend also to be marginal with respect to wheat production and thus increased area estimation errors do not greatly influence the overall production estimation accuracy in the United States. The loss of segments resulting from cloud cover appears to be a random phenomenon that introduces no significant bias into the estimates. This loss does increase the variance of the estimates.